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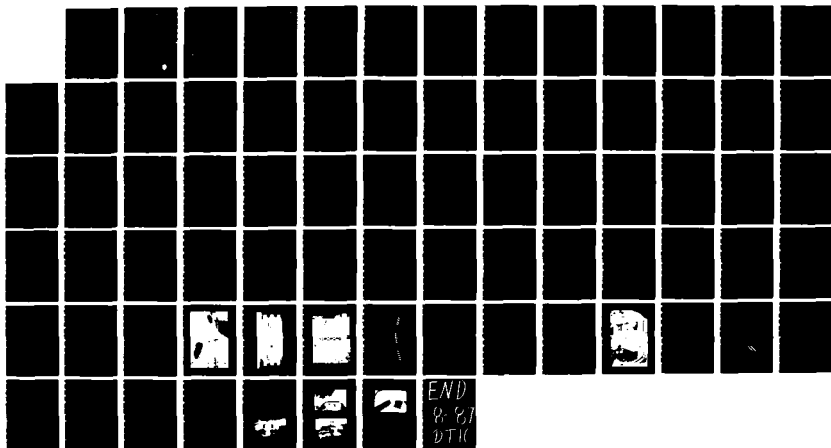
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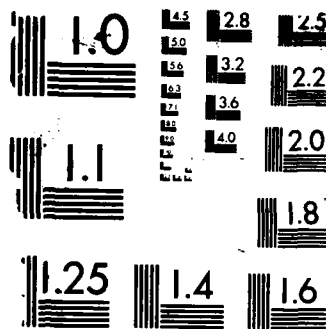
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## **OPTIMIZATION OF PERIPHERAL VISION**

**Julien M. Christensen, Ph.D.  
Robert D. O'Donnell, Ph.D.  
Clark A. Shingledecker, Ph.D.  
Conrad L. Kraft, Ph.D.  
Gary Williamson**

**Universal Energy Systems, Inc.  
4401 Dayton-Xenia Road  
Dayton, Ohio 45432**

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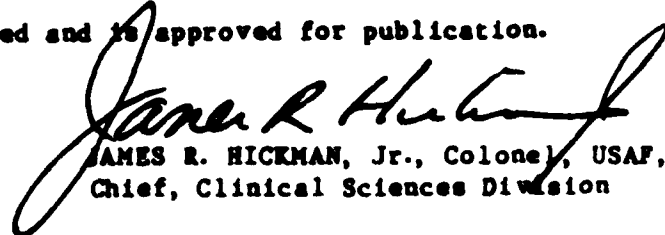
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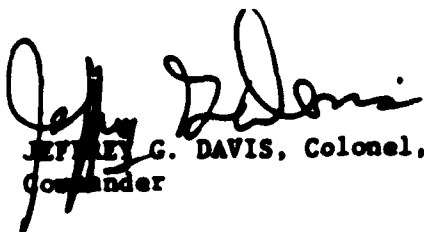
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The Office of Public Affairs has reviewed this report, and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

This report has been reviewed and is approved for publication.

  
BRYCE O. HARTMAN, Ph.D.  
Project Scientist

  
JAMES R. HICKMAN, Jr., Colonel, USAF, MC  
Chief, Clinical Sciences Division

  
JEFFREY G. DAVIS, Colonel, USAF, MC  
Commander

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## CHAPTER 1

### INTRODUCTION TO THE REPORT

Julien M. Christensen, Ph.D.

### INTRODUCTION

The role of peripheral vision has never been well defined in piloting. Pilots frequently acknowledge "seeing something out of the corner of their eyes," but exactly what one should expect to be able to detect, to interpret, and to respond to awaits further definition. Declaration by outstanding visual scientists (cf. Liebowitz, et al., 1983) that the visual system may profitably be considered two systems--the foveal (focal) and the peripheral (ambient)--has directed attention, long overdue, to the capabilities of the peripheral system.

The focal system is generally relied upon to tell us "What is there" through recognition of patterns. To be maximally effective, the stimuli must be well lighted, of high contrast, and easily resolved. In contrast, the ambient system provides information regarding location, attitude, and movement. The images need not be sharp or of particularly high contrast, and can be viewed under relatively poor illumination.

There are interactions between the two systems which should be taken into account in making design decisions. Careful consideration of the requirements and functions of these two systems and more research regarding the ambient system could very well lead to the ambient system being used to assume some of the functions that are now routinely assigned to the focal or foveal system (e.g., attitudinal information). Current use of the 7.5 cm (3 in.) and 12.5 cm (5 in.) attitude indicators (ADIs) in modern aircraft consumes more than one-half of the pilot's visual attention/perception time (Harris, et al., 1980). If a new display/control concept could allocate attitudinal sensing, in part or in its entirety, to the ambient system, additional time might be available for the focal system to be used for other tasks. Thus, it is suggested that perhaps the ambient system can be used as a second primary source of information. One reason that its use in this respect is limited is that the functional characteristics of the ambient system have not been as systematically and thoroughly addressed as have the characteristics of the focal system, and this study very much needs to be done.

The other general function for which the ambient system might be considered is that of confirmation - confirmation of the information being received and processed by the focal system or by the nonvisual systems.

Obviously, a combination of primary and confirmatory functions constitutes a third alternative (e.g., primary for detection of certain warning information and confirmatory as to attitudinal information).

#### A VIEW OF COCKPIT EVOLUTION

The designers of the cockpits of the earliest aircrafts, whether intended or not, took advantage of both the focal and ambient systems. Peripheral viewing was not restricted; pilots received ample stimulation for the ambient system during critical maneuvers, such as takeoff and landing.

Perhaps due to aerodynamic considerations, the cockpits of some aircraft became more and more enclosed. The result was a significant reduction in the number and quality of ambient visual cues that had been available from the early, more nearly "natural" cockpit environments. Simultaneously, there was a proportionate increase in the burden placed on the focal system. Might it be advantageous, at least from the standpoint of total visual system effectiveness, to restore more of a naturalistic cockpit environment? Available research yields very few clues as to the possible advantages of such a design philosophy. One quickly discovers that research devoted to the "Queen of the Senses" does not generally include the entire visual system; the focal system receives most of the attention. The ambient system needs more attention.

#### ORGANIZATION OF THIS REPORT

Before proceeding very far with the idea of assigning more tasks and tasks of greater diversity to the ambient system, it is important to determine whether the underlying anatomical structure is such that it will support such activities. In Chapter 2, Dr. O'Donnell examines the anatomical foundations of the foveal and ambient systems and finds that, indeed, the ambient system would appear anatomically to have potential for assumption of expanded responsibilities, both as to nature and degree. Improvement of ambient functioning through proper training seems, anatomically, well within the realm of possibility.

In Chapter 3, Dr. Shingledecker points out that the ultimate utility of the peripheral system will be determined by an improved understanding of the functional performance capabilities of this system. The role that the peripheral system has assumed, perhaps because of design considerations, may not be an accurate portrayal of the potential roles that the peripheral system can assume under proper conditions. A model is presented whose application would serve to test the performance capabilities of peripheral vision and to assess the suitability of various categories of tasks for assignment to the ambient system.

In Chapter 4, Dr. Christensen examines the issue of whether or not peripheral capabilities can be improved through training. He concludes that there is no doubt whatsoever that individuals can learn to identify stimuli of a

restricted class (e.g., numerals) farther and farther out in the periphery. Whether or not this skill will transfer to rather different classes of stimuli cannot be answered with complete satisfaction. Research is very much needed to determine which dimensional characteristics underlie whatever transfer may occur. The contributions of these characteristics in comparison to the contributions of "response to reduced cues," motivation, and other factors need very much to be sorted out. However, it is reemphasized that improvement in recognition by practice on the same tasks that comprise the real job is certainly possible.

In Chapter 5, Mr. Williamson describes various devices whose designers have endeavored to take advantage of the capabilities of the ambient system. These devices, with training or independent of training, might very well lead to definition and assignment of a significantly expanded role for the peripheral system.

In the Appendix, Dr. Conrad Kraft describes an occlusion apparatus which we feel will have utility both as a demonstration device and as an experimental apparatus.

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Liebowitz, H.W., Shupert, C.L., and Post, R.B. The two modes of visual processing: Implications for spatial orientation, pp. 41-44. In Kellog, R.S., McNaughton, G.B., and Horton, V.W. (eds.), Peripheral vision horizon display (PVHD), NASA Conf. Pub. 2306, NASA Amer Res Ctr, Edwards, CA, Mar 1983.

## CHAPTER 2

### ANATOMICAL FOUNDATIONS OF THE TWO SUBSYSTEMS

R. O'Donnell, Ph.D.

#### INTRODUCTION

The utility of considering the visual system as being made up of at least two functional systems has been well documented (Malcolm, 1984; Leibowitz, Shupert, and Post, 1984; Money, 1984; Leibowitz and Dichgans, 1980). However, it is less generally known that the possible anatomical bases of such a dichotomy have been studied and described for at least as long as the functional observations. Kluver (1942) described in detail the residual visual capabilities of monkeys after a number of cortical lesions. Trevarthen (1968) used the terms "focal" and "ambient" vision for two distinctly different mechanisms identified in primates, and he argued that ambient vision is phylogenetically older, is more prominent in prosimians than in monkeys, and includes all the functions which allow the prosimians to hunt successfully. Such a system would include "the appreciation of visual space, and the orienting movements of the body, head, and eyes needed to move within it" (Stone, 1983, Chap. 11). Trevarthen suggested that focal vision depends on the visual centers of the forebrain and striate cortex, whereas ambient vision depends on midbrain structures.

Other authors have elaborated upon Trevarthen's suggestion, frequently adding confirming evidence. Diamond and Hall (1969) proposed that a "second" pathway, in addition to the well-known retino-geniculo-cortical (RGC) pathway, may be present in all mammals, and that it develops relatively late in phylogeny to serve specialized functions. However, although they believed that this system involves the retina, the midbrain, and the thalamus, they also postulated a cortical component, in contrast to Trevarthen's strictly subcortical system. Almost simultaneously, Schneider (1969) proposed, based on evidence in the hamster, that the two major components of visual function involved a "where is it?/what is it?" dichotomy. The "where is it?" function was presumed to be mediated by the midbrain, and the "what is it?" by the forebrain (including the cortex). Schneider concluded that "animals with lesions of the superior colliculi are capable of normal or near-normal visual discrimination as long as they are not required to make visually guided orienting movements ..." and speculated that, in humans, the "where is it?" system requires the optic tectum, if a visual-motor localizing response is required.

A convincing line of evidence supporting these views involved the discovery of residual visual function in animals deprived of the classical RGC pathway. The destriate monkey retains a great deal of form and spatial vision, being able to localize objects in visual space and to differentiate

figures from background. Weiskrantz (1972, 1978) and Humphrey (1974) suggest that this is mediated by the ambient system, and that the visual cortex normally integrates the activities of the two systems. Presumably, such integration is optimized in response to the task demands, and Weiskrantz suggests that the individual can build up an altered but viable world even in the complete absence of information from the striate cortex.

In humans, there has long been an impression that "some residual visual function survives lesions of the visual cortex, but does not reach consciousness" (Stone, 1983, Chap. 11). Such impressions have received convincing experimental and clinical support. Sanders et al. (1974) and Weiskrantz et al. (1974) reported experiments on a patient who had undergone surgery to one occipital lobe, resulting in a macular-splitting hemianopia. This subject showed considerable ability to reach and touch a light presented to the blind hemifield, and to distinguish between simple forms if they were large enough. They termed this phenomenon "blindsight." Singer et al. (1977) provided an even more elegant demonstration of retinal sensitivity in "blind" areas by showing a localized alteration of the visual threshold even though the subjects were not aware of any adapting stimulus. Barbur et al. (1980) showed that velocity sensitivity and spatial localization were little affected by a lesion in the visual cortex of one hemisphere, although there was little residual ability to discriminate shape or size.

In view of the data just presented, it appears that there is compelling evidence to postulate differing anatomical bases for the two functional visual systems. The focal system appears to be generally centered about the RGC pathway. This system provides high resolution of spatial patterns, along with "conscious" visual perception. The ambient system is less well defined anatomically, but appears to contain midbrain structures, along with some cortical projections. It appears to mediate visual guidance of gaze and limb movements, limited pattern discrimination, and certain subconscious reflexes such as pupillary response to light. The following sections of this chapter present an overview of the current view on the anatomical bases of both systems, at least as they are presently envisioned. It should be noted that most of what is known or postulated about the peripheral (ambient) system comes from animal studies, and it is likely that the picture will be different, in detail if not in substance, in humans. The chapter ends with some admittedly speculative ideas on interactions of the two systems with each other and with other senses, and how their capabilities might be enhanced.

#### PRIMARY VISUAL PATHWAYS

The following is a summary description of the so-called "primary" visual pathways. These deserve the term primary because they represent the classically studied system which, for many years, was thought to be the only visual system of importance. However, it must be recognized that this system is now known to be primary only in the sense that it appears to be the one on which

humans primarily depend for performance of fine visual-motor function, or for fine visual discrimination. In that sense, the system to be described here constitutes the "focal" system previously mentioned.

#### RETINAL LAYERS

The principal anatomical structures of the retina are the rods and cones. As is well known, the cones mediate color vision, are located principally in the center of the retina, and are less sensitive than the rods. There are about 1500 cones per square millimeter in the central fovea, and each cone is probably connected to an individual ganglion cell and nerve fiber which, in turn, connect it to the lateral geniculate nucleus and thence to the cortex. There are perhaps as many as 6 million cones in each eye. Cones are formed by a single membrane which is folded back and forth on itself without any surrounding membrane (Knowles, 1982).

The rods occupy a greater retinal area than the cones, although they are absent in the central one degree of the visual field. The rods are known to be achromatic, to be more sensitive to absolute quantities of light than cones, and to operate principally through the breakdown of rhodopsin. There are over 100 million rods in each eye and, unlike cones, each rod is formed by a series of separately joined membranes which are surrounded by an outer, scotopic membrane layer. The rod response is relatively slow (about 100 ms) as compared to the cone's response. However, each rod is linked electrically with neighboring rods, producing a "spread" of firing if a single rod is stimulated. The greatest concentration of rods occurs about 20 degrees from the central retina, with few or no rods in the central one degree.

After the rods and cones, there are multiple retinal layers. The outer plexiform layer contains horizontal cells, which apparently mediate lateral inhibition, and bipolar cells. The inner plexiform layer contains amacrine cells (whose function is uncertain) and many types of ganglion cells in which the signals going up the optic nerve are generated. In primates, these retinal ganglion cells project to many subcortical structures. The best known of these is the dorsal lateral geniculate nucleus and the superior colliculus. However, it is important for the present purposes to remember that projections are also found in the suprachiasmatic nucleus of the hypothalamus, the lateral and dorsal terminal nuclei of the accessory optic system, and the pretectal and olivary nuclei of the pretectum (Weller and Kass, 1981). The optic nerve exits the retina and eyeball at the so-called blind spot, and travels inward to the center of the brain.

#### NERVES, TRACTS, AND MIDBRAIN STRUCTURES

The optic nerves carry neural signals from each eye centrally in the brain, maintaining a relatively accurate topographical representation of the retina. At the optic chiasm, however, this representation becomes decussated. Signals which originated in the nasal half of each retinal hemifield are

shunted to the opposite side of the brain, while signals which originated in the temporal half of each retina continue to the same side of the brain. Thus, after the chiasm, the optic "tract" on each side of the brain contains signals which originated in both eyes.

The ipsilateral optic tract contains fibers which travel to the lateral geniculate synapse in layers 2, 3, and 5, while contralateral fibers terminate in layers 1, 4, and 6. Fibers from the fovea end predominantly in layers 3, 4, 5, and 6, and rarely in layers 1 and 2. Fibers which originated in the retinal periphery end in "lower margins of the body where layers tend to be less distinct" (Willmer, 1982). Although, as previously mentioned, some retinal firing originating in the ganglion cells is transmitted to subcortical areas other than the geniculate, it is likely that these arise from axon collaterals or from a very small population of ganglion cells, because it has been shown that nearly all retinal ganglion cells travel to the geniculate (Weller and Kass, 1981). In any case, at least some retinal fibers also travel to the superior colliculus and to the pretectal area. Neurons from this pretectal area go to the Edinger-Westphal nucleus, and from this source the third cranial nerve originates and innervates some of the extrinsic eye muscles, the ciliary muscles, and the dilator pupillae. It is clear, therefore, that between the rich geniculate connections and the colliculus, this primary visual system is well suited to precise visual tracking and object resolution.

#### PRIMARY CORTICAL AREAS

Optic radiations carry impulses from the geniculate to the primary visual cortex (area 17), and all geniculate fibers terminate in layer IV of the cortex (Willmer, 1982). Each eye is represented alternately in area IVc of area 17. However, the fovea monopolizes a disproportionately large part of the visual cortex, with a very small area being given over to the periphery. Within area 17 itself, there appear to be vertical columns of cells, which operate with some degree of independence. In some cases, each column appears to specialize in some orientation feature of the visual environment, so that it is activated only, or predominantly, by specific kinds of visual stimuli. The functional implications of this specificity will be discussed further in this report when different kinds of functional retinal cells are considered.

#### SECONDARY VISUAL PATHWAYS

Although it is clear that the primary visual pathways just described constitute the major source of detailed, conscious information for the human, there is abundant evidence to suggest that this geniculocortical system "operates in parallel with another major set of neurons involving the midbrain, the posterior complex of thalamic nuclei, and the visual cortex" (Stone, 1983, Chap. 8). In cats and primates, at least, the posterior association cortex



shows an elaborate multiple representation of the visual field. At least 13 areas have been identified "... each containing a representation of at least part of the visual field, and still other cortical areas, well beyond the visual association cortex even most generously defined, have been shown to contain neurons responsive to visual stimuli" (Graybiel and Berson, 1981). In addition, these relatively discrete visual response areas are paralleled by others in the extrageniculate thalamus (especially in the nucleus lateralis posterior and pulvinar). It has been hypothesized that these "family clusters" of visual neurons outside of the primary visual system "are characterized by a preferential relation to the tectothalamocortical and pretectothalamocortical channels and to the transthalamic circuitry of the striate recipient zone" (Graybiel and Berson, 1981). Further, it appears that these family clusters, while relatively independent of each other in terms of corticocortical links, are richly interconnected among the members of a single family.

Among these many possible alternate pathways, several involving the posterior thalamus appear to be most pervasive in animals, having been at least partially traced in the cat, New- and Old-World monkey, opossum, hamster, bush baby, lemur, and rat (Stone, 1983, Chap. 8). In the cat, Berson and Graybiel (1978) have suggested at least three major thalamic paths by which retinal activity can reach the cortex without going through the lateral geniculate nucleus. The first of these paths involves the lateral part of the pulvinar nucleus. This area receives direct retinal input, and projects to area 19 and area 21a. The more medial part of the pulvinar nucleus receives projections from the pretectal region of the midbrain, and projects to area 19. This pathway is therefore even more legitimately considered an extrageniculate route, since it is even further removed from the primary path. The third route is further medial, in the medial part of the lateral posterior nucleus. This area receives strong inputs from the superior colliculus, and its cells project to area 19. While these are not the only areas which have been identified in the cat, they provide firm evidence of the existence of pathways lying outside the lateral geniculate nucleus which can operate in parallel with the geniculocortical pathway.

Similar pathways have been identified in the monkey, with one important difference. Some of the cortical projections of these areas appear to terminate in area 17 and, at least in some cases, in area 18 (Stone, 1983, Chap. 8). These terminations, however, are in different layers than the terminations of geniculate afferents. It appears that the superior colliculus projects to the inferior pulvinar nucleus in both the squirrel and rhesus monkey, and that this region projects to layers 1 and 6 of area 17, and to layers 1, 3, and 4 of area 18 (Stone, 1983, Chap. 8). Since strong interconnections have been shown between the lateral and inferior parts of the pulvinar, it has been suggested that these two sections of the thalamus may act as a thalamoprestriate pathway running parallel to the primary geniculocortical pathway. The pathway displays characteristics which would suit it well as a "substrate for spatially organized visual behavior," since it is topographically organized in the monkey and the cat, at least, and appears to be a common feature of the

mammalian brain (Stone, 1983, Chap. 8). The appearance of these projections in cortical areas generally thought to be utilized by the primary visual system suggests a capacity for integration of information from the two visual systems in higher species, and justifies speculation concerning the mode of such interaction.

The tectopulvinar system has been known for some time, but its significance has never been perfectly clear. Among the more confusing projections from this structure are those that travel from the posterior pulvinar nucleus to unmapped temporal lobe regions (Weller and Kass, 1981). Three visually responsive temporal lobe areas have been identified in the Macaque: the Middle Temporal (MT) Area, the Inferior Temporal (IT) Area, and the Superior Temporal Polysensory (STP) Area (Gross, et al., 1981). The visual stimuli to which these areas respond have been studied, and may suggest the functions subserved by these secondary visual areas. The MT and IT, for instance, respond only to visual stimuli, whereas the STP is responsive also to auditory and somesthetic stimuli. Similarly, both MT and IT respond to stimuli in the central field of view, with STP responding over a wider visual receptive area. The MT area may also be involved in signaling movement in depth. Lesions of the area do not, however, impair acquisition or retention of visual pattern discrimination, whereas lesions of IT regions cause severe deficits in visual discrimination learning, while leaving acuity, visual fields, and psychophysical thresholds all normal. These results lead to the speculation that MT and IT may be more involved in "focal" types of activities. The STP area, on the other hand, shows little sensitivity to size, shape, orientation, color, or contrast of the visual scene. It is responsive to moving stimuli, and shows some directional sensitivity. Removal of this area results in no deficit in visual discrimination learning, although there may be deficits in a polysensory task such as a visual-auditory association. Thus, this area is not exclusively visual, shows no visuotopic organization, and appears involved in motor acts.

Such observations, although incomplete and obviously sketchy, can justify speculation that extrastriate areas participate in parallel and equally in the processing of visual information through the primary visual system. Likely candidates for such areas involve the posterior thalamus, especially the pulvinar and the lateral posterior nucleus, and areas of the temporal lobe such as the Superior Temporal Polysensory Area. Interconnections between the thalamic structures (such as the lateral and inferior pulvinar), as well as the rich interconnections between cortical structures, argue for intimate communication and interdependency between primary and secondary visual system input, as well as between visual input and other sensory modalities. Of particular interest in this regard is the interaction between visual and vestibular input, which will be discussed in more detail in a later section.

## FUNCTIONAL ORGANIZATION OF THE VISUAL SYSTEM

### Nerve Cell Systems

It has been argued that major components of visual perception (such as focal and ambient vision) can best be understood by looking at systems of nerve cells. This is in contrast to the view that visual neurons act as "feature detectors," and that visual perception consists of a synthesis of these features in the environment (Stone, 1983). Indeed, families of such cells have been identified in the primate. Among the best known are the "W, X, and Y" cells. These ganglion cell groups terminate in different layers of the cortex (Graybiel and Berson, 1981), and appear to subserve different functions, even in the primary, retinogeniculate pathway. In monkeys, for instance, X cells go to the parvocellular layer of the geniculate, and are more numerous than any other type of cell. They show a sustained discharge to a steady stimulus, and are color-opponent, although they have a small receptive field and conduct at moderate velocities. The X cells have been postulated to be responsible for the orientational anisotropy, or "oblique effect," in which the visual system is more sensitive to contours oriented vertically or horizontally than to those oriented obliquely (Stone, 1983). Interestingly, this effect is maximal in the fovea, and decreases progressively with retinal eccentricity.

The Y cells are fewer in number, and go to the magnocellular layer of the geniculate. These cells show a larger receptive field than the X cells, conduct impulses rapidly, and display a broad responsiveness to color. They respond briefly to a change in a steady stimulus. Some Y cells have been shown to send collaterals to the superior colliculus.

In some ways, W cells are the most confusing of the three groups. There are few of these cells in the primate, they display a slow conduction velocity, and their function is not yet understood. They have not been found at all in the geniculate, but are well represented in the superior colliculus (Weller and Kass, 1981). These observations are significant in the present context because of the fact that striate lesions, which would destroy the primary visual system, would wipe out all X cells, but would not affect all Y and W cells. It is possible, therefore, that some of the visual functions represented by the ambient system may be mediated by these cells or others showing similar independence from the primary system. If so, study of the firing characteristics of such cell families may well help define the limits of the ambient system.

### TOPOGRAPHICAL CONSIDERATIONS

Similarly, some definition of the capabilities of the two systems may be derived from study of the topography of the fovea and periphery in the cortex, and its relationship to function (Allman, et al., 1981). In the monkey, the central 10 percent of the visual field occupies 75 percent of the dorsolateral

crescent visual area. This area shows optimum response to slower moving objects (10 degrees/second). On the other hand, the central 10 percent of the visual field occupies only 4 percent of the medial visual area, whereas the periphery is better represented in this area than anywhere else. This medial area shows optimum response to much faster movement (100 degrees/second).

As previously mentioned, the lateral and medial parts of the pulvinar nucleus of the thalamus project to areas 19 and 21 in lower animals, while the inferior pulvinar nucleus projects to areas 17 and 18 in the monkey. These projections are usually found to be independent of the geniculate projections to the cortex.

Although no direct connections can be drawn, it is tempting to speculate that firing from the periphery activates primarily Y and W cells, which follow an extrageniculate route, by way of the thalamic pulvinar nuclei, to the same area in the occipital cortex serving as receptor areas for the primary visual system. In addition, however, these cells also send collaterals to other cortical areas, most notably temporal (and possibly parietal) areas, which provide ancillary processing. Such ancillary processing would be unconscious, and would serve the function of "filling in" context or "surround" information as an adjunct to the data supplied by the primary visual system. Data on the possible existence of "Polysensory Areas" further indicate that these secondary visual areas may in fact be linked to other sensory receptive areas, and that these could play a significant role in the integration of visual information with other sensory data.

Although many sensory interactions are possible, one has received considerable attention both in the basic and applied literature: the visual-vestibular interaction. For that reason, this possible interactive system is described next.

#### VISUAL-VESTIBULAR INTERACTIONS

The vestibular apparatus is well tuned to receive and signal translational movements of the head from side-to-side or fore-and-aft. However, unlike fish, humans have a poor perception of up-and-down motion, and have only a 50/50 chance of accurately reporting such movement even through large distances (Malcolm, 1984). The organs which are sensitive to such translational and rotational motion are the cristae of the semicircular ducts and the saccular and utricular maculae. These structures exit the vestibular apparatus through the VIIIth nerve, and proceed to the ipsilateral vestibular nuclear complex. Collaterals enter the cerebellum, where most terminate as mossy fibers in the ipsilateral flocculus, nodulus, and uvula. A few of the fibers go to the contralateral vestibular cerebellum. In addition to this firing directly from the vestibular apparatus itself, the vestibular nuclei receive information from the cerebellar cortex, from other cerebellar nuclei, from the reticular formation, and from ascending spinal tracts. It can be seen, therefore, that

the vestibular system is "a complicated integrative centre in which signals from the vestibular apparatus...are combined with signals from joint receptors" (Benson, 1982).

There are also numerous connections between the various vestibular centers and the visual apparatus. Some of these connections are not with the primary visual pathway, but are directly connected to the eye muscles. These, as noted earlier, are also innervated by neurons which travel from the retina to the superior colliculus and pretectal area, and thence to the extrinsic eye muscles. The vestibulo-ocular connections are so important that one of the principal functions of the vestibular system appears to be "to stabilize the eyeballs in the skull" (Malcolm, 1984). The plane of each pair of semicircular canals is precisely the same as the plane of rotation of the individual pairs of muscles connected to the eyeballs. These canals are known to generate signals which are proportional to the instantaneous velocity of the skull, and to send them directly to the muscles controlling the direction of gaze.

All of these interactions deal with the influence of the vestibular apparatus on the visual response. It is well known, however, that the opposite direction of effect is also possible. Visual stimulation can cause severe vestibular effects, and there is abundant evidence that these effects are most severe when the peripheral visual system receives atypical or conflicting information (Liebowitz, Shupert, and Post, 1984).

#### SUMMARY AND IMPLICATIONS

This review clearly establishes an anatomical foundation for the two functional visual systems which have been postulated. It should be noted, however, that the evidence linking the non-geniculate systems with the peripheral retina is not overwhelming. Logically, and from a functional analysis, one can easily relate the two. However, except for the indications that the periphery is well represented in temporal and parietal lobe cortical areas, the link between the periphery and extrageniculate pathways has not been emphasized.

Similarly, caution is necessary in extrapolating the animal results described in this report to the human visual system. As noted, the final human structure is likely to be similar to those isolated in animal models. However, since uniquely human types of information processing are of interest in the present context, it would be unwise to depend on animal and human systems being identical in generating hypotheses.

With these cautions noted, it will be productive to consider and emphasize some of the facts noted. One of the most striking observations is that the two systems appear to act both independently and interactively. The animal data and the human observations confirm the fact that the extrageniculate systems appear capable of acting alone, and there is no anatomical reason to believe that this would not be so. On the other hand, the possibility that there may be interconnections between thalamic structures suggests that the

primary and secondary systems could be in communication at all times. In addition, as shown in this report, the visual system has rich interconnections with other sensory systems, most obviously the vestibular system.

The implications of these observations are that much greater attention must be given to the interactions both BETWEEN and WITHIN sensory modalities than has been done in the past. It is likely that no sense modality is unitary. Secondary systems have been identified for audition, and it is not unlikely that each sense may have both primary and secondary components. The study of any sense modality, and most particularly vision, without considering the contribution of the secondary systems is destined to be incomplete at best, and perhaps entirely misleading at worst.

These observations suggest the need for a series of studies which carefully control the input of all aspects of a given sensory modality, as well as to all other sensory modalities which may interact with the one of interest. Ideally, this control should be defined in terms of the physiological mechanisms underlying the processing of each type of input. However, since these mechanisms are not well enough understood, some assumptions will be necessary, and the control will have to be exercised in terms of likely mechanisms underlying the functional capabilities of the system. Such studies would involve, as typical independent variables, the retinal location of the stimulus; the orientation, speed of movement, size, contrast, and spatial frequency of the stimulus; and the "meaning" of the stimulus to the person. Other factors, involving interactions with other sensory systems (proprioceptive, kinesthetic, vestibular, auditory, etc.), must be completely controlled. These studies would have as their goal the establishment of the precise functional limits, both topographically and parametrically, of the primary and secondary visual systems. They would constitute a mutually fruitful system in the sense that anatomical clues would suggest stimulus parameters, while results of the stimulus parameter studies would provide more data on the anatomical loci.

Of equal or greater importance from a practical sense, it is desirable to define the performance limits of the secondary visual system. It was noted in the studies by Weiskrantz (1974) that humans were able to perform discrimination tasks using peripheral vision alone if the stimuli were large enough. The peripheral system, perhaps through its access to the focal system at the brainstem level, may have access to cognitive and perceptual processing capabilities which are not normally employed. Weiskrantz notes that an individual lacking foveal vision was able to behave as if the visual world was altered, but quite adequate. Put differently, it may be that the secondary visual system is capable of much more than it normally performs, and that the actualization of such abilities may depend on the demand placed upon the system.

If this supposition is true, it may very well be that the peripheral visual system is capable of training and expansion under the appropriate conditions. To explore this possibility, it is desirable first of all to identify which skills the human can carry out in the periphery. Such identification should not be limited to exploration of well-accepted peripheral functions such as motion or velocity detection. The possibility should be explored that

cognitive processing of various types might be possible using peripheral vision alone. This hypothesis is defensible, considering the interactions between the primary and secondary visual systems. Once the range of abilities has been defined for the secondary system, a training regimen involving increased demands on the secondary system, improved strategies, and practice should be employed to determine whether the capabilities of the system can be increased.

A final consideration with respect to the secondary system deals with its apparently "unconscious" nature. It has been pointed out that the "ambient" system provides a great deal of contextual information. Yet, such information appears never to reach the conscious level. Emotional responses may be more difficult to study than performance, but the implications of emotional factors on performance should not be overlooked. It is known that, for the auditory system, emotional responses to sound may be obtained from animals previously conditioned to auditory stimuli, even when the primary auditory cortex has been destroyed. The secondary auditory system therefore seems capable of independently affecting emotional experiences. It would appear worthwhile to explore systematically the contribution of the secondary visual system (as well as other secondary sensory systems) to the overall interpretation of the environment in particular contexts, such as in high-stress flight. To be manageable, such studies would have to be highly controlled in laboratory situations. However, there is reasonable hope that the basic studies would eventually generate a rich enough set of hypotheses and data to enable one to perform operationally relevant studies.

In summary, the anatomical evidence concerning the existence of two separate visual systems is strong enough to support a broad range of studies which explore the parametric limits of each system, the plasticity of the systems with respect to demand and training, and the contribution of the secondary system to unconscious, emotional, or motivational effects. There is a reasonable possibility that such studies could lead to a significant expansion of human visual capabilities.

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## CHAPTER 3

### FUNCTIONAL PERFORMANCE CHARACTERISTICS OF PERIPHERAL VISION

Clark Shingledecker, Ph.D.

#### INTRODUCTION

Current trends in aerospace technology clearly indicate that the cockpits of future fighter aircraft will have to be very different from those which were developed for present operational systems. This unavoidable revolution in cockpit design is being driven by rapid advances in the development of high-speed airborne computers, sensors, and communications systems. Together with enhanced weapons, electronic warfare techniques and faster, more maneuverable airframes, these sophisticated technologies are combining to form the very feasible engineering concept of a "super system" capable of sustained combat with a level of mission effectiveness that would be an order of magnitude greater than that achievable in current aircraft.

A major impediment to the ultimate realization of this "super system" is the limited sensory, perceptual, and cognitive capability of the human operator. Despite the advent of automated subsystems, it is believed that the pilot will remain an indispensable component of future fighter aircraft who must continue to contribute on-board intelligence, flexibility, and supervisory decision skills to system performance. In order to provide these qualities, the pilot must be able to acquire all of the relevant information made available by advanced technologies and process it efficiently to achieve a superior level of situation awareness. Unfortunately, traditional approaches to cockpit display design are already approaching the limits of their capability to present information in a manner which permits the typical pilot to maintain a current understanding of primary system, environment, and combat variables.

Solutions to the problem just outlined will require intensive efforts on several scientific fronts. Methods must be developed to select pilots for future aircraft who are most able to meet the attentional and cognitive demands of these systems. Likewise, training techniques are needed which will allow pilots to achieve and maintain peak levels of skill proficiency. Perhaps most importantly, however, new approaches must be adopted for the design of cockpit display media and formats which will enhance pilots' innate capabilities and permit them to perform control, monitoring, and decision tasks at optimal levels of mental workload.

One of the design approaches that may be taken to expand the information processing bandwidth of the pilot is to explore the possibility of greater utilization of available sensory and perceptual systems for information input. It has been estimated that 90 percent of aircraft operation tasks are mediated

by foveal vision. One argument that has been posited is that at least some proportion of the excessive workload associated with military piloting tasks may be attributable to an overload of the central visual system. According to this hypothesis, the pilot's task demands would be reduced by allocating some tasks that are normally served by foveal vision to alternate sensory systems.

Such "sensory substitution" is not a new concept. In the 1950's, a system known as Flying By Auditory Reference (FLYBAR) used dichotic tone cues varying in pitch, intensity, and interruption rate to provide information on aircraft turn, bank, and airspeed (Morgan et al., 1963). More recently, synthesized speech has been examined as an alternative for certain visual flight displays (e.g., Wickens et al., 1983). In other areas, dynamic auditory displays have been used as visual substitutes for blind mobility and specialized visual and tactile displays have been developed to permit speech perception by the deaf (Singledecker, 1981).

While poorly publicized, these attempts at sensory substitution often have met with only moderate success. One explanation for the limited effectiveness of sensory substitution experiments is that individual sensory/perceptual systems may be innately and physiologically bound by human evolution to specific categories of tasks. This hypothesis was argued very strongly by Lieberman, Cooper, Shankweiler, and Studdert-Kennedy (1968) to account for the failure of efforts to design effective visual analog displays of spoken language. According to the authors, the auditory system (for example) may be neurologically specialized for speech perception and other modalities will never be able to achieve its speed and accuracy when dealing with a connected speech signal.

Regardless of the potential validity of this hypothesis, it is an empirical fact that nearly all sensory substitution displays produce some non-zero level of performance success on tasks which are normally mediated by a different input modality. This fact suggests that further enhancement of performance may be possible through appropriate recoding of the information presented to the substitute sensory system. When considered from this point of view, the problem of finding ways to make effective use of alternate sensory systems becomes a human factors issue. That is, its solution will involve searching for an optimal allocation of tasks to alternate sensory systems, developing useful data presentation formats, and compensating for sensory limitations to maximize the performance capabilities of the human operator.

The purpose of this chapter is to examine a special form of sensory substitution from a human factors standpoint. Specifically, in the following sections consideration is given to the roles that peripheral vision may play as a substitute for foveal vision in tasks that must be performed by pilots during military aircraft operation.

## PSYCHOPHYSICAL VS. PERFORMANCE CHARACTERISTICS

In order to assess the possibility that peripheral vision could be called upon to adopt functions normally subserved by central vision, it is necessary to consider the difference between basic measures of the qualities of a sensory system as obtained from psychophysical experimentation, and measures of human performance on a task which is mediated by a specific sensory system. Psychophysical studies are aimed at exploring the correlation between environmental events and some corresponding psychological experience. Thus, for example, as the physical variable of light intensity is varied, psychophysicists are interested in the way in which the corresponding psychological variable of brightness changes. Normally, such psychological experiences tend to parallel physical variations according to mathematically describable adjustment functions. These adjustment functions precisely define the modifications that human sensory and perceptual systems impose on physical reality, and can be used to compare input modalities in terms of their relative sensitivities to physical energy parameters.

Despite the precision of psychophysical data, they define only the boundaries of sensory experience and can be dissociated from the quality of measures of performance that are obtained when a sensory system is engaged in mediating specific task performances. For example, while vision is a primary source of input for a variety of important tasks, the psychophysically determined quality of vision is not a good predictor of performance on all of these tasks. Visual impairment is closely related to reading performance. Even small losses of acuity can have profound effects on a person's ability to acquire information from a printed page. However, such a strong correlation can be misleading if it is assumed to extend to other highly visual skills. The ability to walk in a purposeful manner and to orient one's self in space is minimally affected by even major visual impairments, and suffers catastrophic decrements only when the visual system is completely lost.

The distinction between basic psychophysical and functional performance measures of sensory capability illustrated by the previous example may be equally applied to the problem of evaluating the capacity of peripheral vision. Psychophysical comparisons of foveal and peripheral vision clearly show a superiority of foveal vision on the majority of sensitivity parameters. However, these measurements may be revealing very little about the functional ability of peripheral vision to assume the sensory responsibility for tasks which are normally foveated. In order to address the issue of display design for peripheral vision, consideration must be given to research which has gone beyond psychophysical metrics to evaluate the capabilities of the peripheral subsystem in performing psychomotor and cognitive tasks.

## PERIPHERAL VISION PERFORMANCE CAPABILITIES

Two alternative approaches can be taken to investigating and exploiting the performance characteristics of peripheral vision. The first of these may be labeled the "direct performance comparison" method. Using this approach,

the researcher seeking to evaluate peripheral vision as an input modality performs experiments which compare measures of speed and accuracy of performance when various visual input tasks are presented to the foveal and peripheral fields. By comparing the two visual subsystems across different types of performance activities, the researcher should be able to identify the task categories in which each excels, as well as those which are performed equally well by central and peripheral vision.

Unfortunately, a search of the experimental psychology literature reveals almost no data which have been generated using the direct performance comparison method. The rare examples which do exist are indirect comparisons that must be extracted from more complex experimental designs aimed at different research issues. This was the case in a study by Hosman and Van der Vaart (1981) which was concerned with the contribution that additional peripheral cues make to foveated tracking tasks. The fortuitous inclusion of a peripheral vision-only tracking task as a control condition permitted evaluation of the two subsystems. Interestingly, in comparison to the foveal vision conditions, the peripheral display produced only a one-degree increase in the standard deviation tracking error score.

It should be noted that the historical paucity of empirical research directly comparing peripheral and foveal vision performance capabilities is not really surprising. The majority of human performance research studies are motivated by realistic issues in human behavior. Since humans typically foveate the primary stimulus of a task which commands their attention, the presentation of such tasks to the peripheral field would appear to have little ecological significance. Increasing demands for improved utilization of available sensory channels for cockpit information display should change this state of affairs, and it can be expected that more direct comparison performance studies will be conducted in the future.

The second approach that has been used to develop an understanding of the performance capacities of peripheral vision can be characterized as a "naturalistic" method. Up to the present, a majority of knowledge about the functional capabilities of peripheral vision has been derived from an analysis of the "natural" role that it plays in mediating behavior. Held (1970) and Leibowitz and Post (1982) developed a concept of the visual system which describes it as having two modes of processing. The "focal" mode answers the questions of what is being observed, while the "ambient" mode provides answers about where the observer is in space and about movement of the observer and the environment.

According to this model, the ambient mode of processing is served mainly by the peripheral visual field. Thus, it appears that peripheral vision's "natural" role is to transmit information to the brain about the orientation of the body in space during movement. Peripheral vision provides these data from large stimulus field patterns which are not strongly dependent on precise image quality or high levels of illumination. Furthermore, Leibowitz (1982)

argues that the ambient visual functions mediated by peripheral vision are performed in an automatic fashion (i.e., they do not require attentional capacity).

The orientation information provided by peripheral vision acting in an ambient mode clearly defines a naturalistic approach to the development of peripheral vision displays in which simple motion and direction cues would be provided to enhance pilot performance. The Malcolm Horizon and other experimental display techniques have been constructed on this principle and appear to be capable of providing flight control information with reduced workload requirements.

### RESEARCH NEEDS

While displays which make use of natural functions are of obvious value, they may not be taking full advantage of the performance capabilities of the peripheral visual system. As noted earlier, very little is known about the potential capacities of peripheral vision when acting in a "focal" mode, performing tasks which are normally foveated. Although peripheral displays for such primary tasks would have to be designed to compensate for the relatively poor psychophysical qualities of the peripheral subsystem, it is possible that such minor adjustments would be rewarded by an enhancement of the pilot's sensory input capacity. In addition, the hypothesis that peripherally presented information is processed at a more automatic level than foveally presented information suggests that assigning tasks to the peripheral system could result in a genuine reduction in the total workload demands placed on the pilot.

The foregoing discussion indicates that a systematically applied research effort is needed to evaluate the full performance mediation capabilities of the peripheral vision subsystem. This research would be conducted using the direct comparison method and would determine the types of information processing tasks which can be accommodated by the peripheral system. In addition, the effort should investigate the relative difference between multiple task performances when performed by foveal vision and when shared by the foveal and peripheral systems. The outcome of this research would be a set of design guidelines for the optimal application of peripheral displays to cockpit tasks.

In order to provide generalizable design guidelines, such a research effort requires a theoretical model of human performance capability to define experimental questions and direct the selection of tasks for presentation to the two visual subsystems. A framework which appears to be particularly well suited to the issue is the Multiple Resource Theory as described by Wickens (1981). This model of human attentional capacity decomposes information processing capability into a number of dedicated, structure-specific resources which are selectively utilized during the performance of a task. According to the theory, performance will vary as a function of the demands that a task places on individual resources. Thus, overload will occur and performance

will be limited if a task places excessive demands on one or more resources. Likewise, the potential for multiple tasks performance will be determined by the degree to which two tasks share common resources.

Supporting evidence has been obtained to indicate that separate, non-shared resources are associated with perceptual, central, and response stages of information processing. In addition, these resources appear to be subdivided so that individual capacity pools can be attributed to visual and auditory input modes, manual and vocal output modes, and spatial and linguistic central processing codes.

Beyond its description of mental capacities, this model provides guidance for empirical research on the task performance capabilities of peripheral vision. First, the model suggests that in order for peripheral vision to offer additional performance capability to the operator, evidence must exist to indicate that it forms an input resource which is at least partially dissociated from foveal vision. To test this hypothesis, the model would suggest dual task studies presenting separate simultaneous tasks to the foveal and peripheral fields to assess the degree of interference between the two subsystems. Such data would determine the conditions under which peripheral vision provides a true "extra" input channel and would contribute in a fundamental way to display guidelines.

Second, the multiple resource theory contains corollaries dealing with S-C-R compatibility and task integration which define additional experimental inquiries that should be made. S-C-R compatibility refers to a relative enhancement of performance that is achieved when specific input, central processing and response output resources are combined to perform a task. In the current form of the multiple resource model, S-C-R compatibility effects are obtained when visual/spatial/manual and auditory/verbal/vocal combinations are used. If peripheral vision offers a resource pool in addition to those already identified in the model, it is possible that unique combinations with central processing and response resources will produce different compatibility effects. Research designed to test this hypothesis would further improve the proposed display guidelines by defining optimal task designs for presentation to peripheral vision.

Task integration effects in the multiple resource theory refer to performance improvements which are achieved when two tasks which share common resources are somehow integrated rather than performed separately by the operator. For example, two unidimensional tracking tasks presented separately are performed less well than the same tasks when combined as a two-dimensional task. This integration phenomenon suggests that research directed toward design guidelines for peripheral vision displays also could be extended to determine the optimal combination of simultaneous tasks for assignment to the peripheral and focal subsystems.

## SUGGESTED RESEARCH

The previous discussion described the need for model-based research on the performance characteristics of peripheral vision. This final section outlines a demonstration research facility as well as a set of experimental conditions defined by the multiple resource theory model which could be used to develop comprehensive design guidelines for future peripheral vision displays.

In its most rudimentary form, the research facility would consist of a subject testing station for the presentation of a set of standard performance tasks to the peripheral and foveal visual fields. These tasks would appear on three cathode-ray tube (CRT) displays arranged to provide stimuli foveally and at variable distances from the fovea in the left and right peripheral fields (see Figure 1). Two inexpensive microcomputers would be used for task presentation and for recording of subject responses made on discrete and continuous

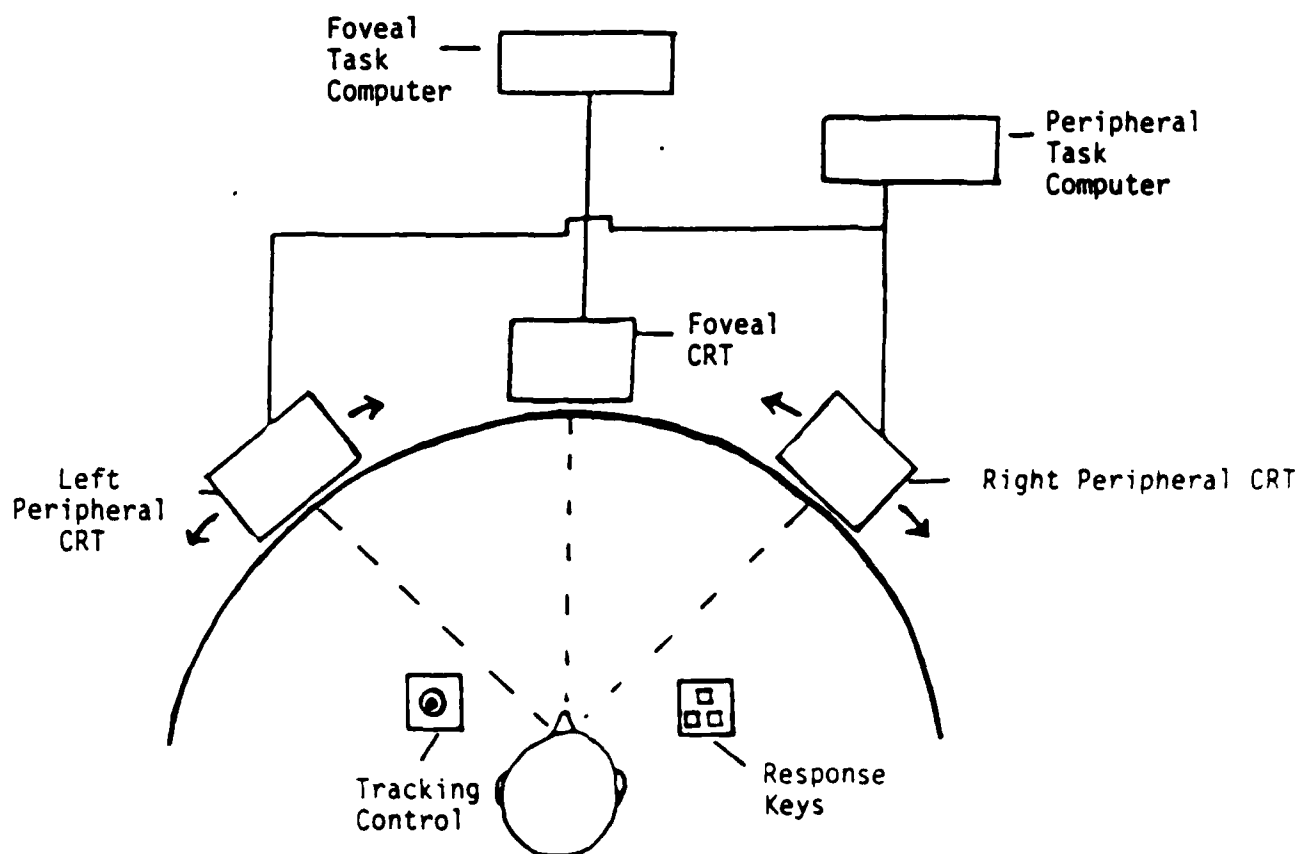


Figure 1. Demonstration research facility for the development of peripheral vision display design principles.



control devices. A more advanced version of the apparatus would include equipment to detect the direction of the subject's gaze. This equipment would permit data to be rejected which is not obtained while the subject is fixating on the central display. In addition, it could be used to investigate the eye movement strategies of subjects attempting to perform simultaneous central and peripheral tasks.

The overall system just described would be used in a series of experiments designed to assess the performance capabilities of peripheral vision. These experiments would be based on a standard set of visual performance tasks selected to tap individual information processing resources diagnostically, as suggested by the multiple resource theory. For preliminary work, the following tasks would be implemented on the system: 1) Visual monitoring (perceptual resources); 2) Memory scanning (central, symbolic resources); 3) Mental rotation (central, spatial resources); and 4) Unstable tracking (manual response resources).

These tasks would be employed in both single and dual task studies to develop peripheral vision design guidelines. Single task studies would be performed to compare foveal and peripheral vision performance of tasks differing in central processing and response resource requirements. In these experiments, all psychophysical limitations of peripheral vision would be controlled by adjusting stimulus size and contrast parameters when tasks were presented in the peripheral field. The goal of the experiments would be to determine the types of tasks to which peripheral vision is most suited.

Succeeding dual task studies would be performed to address a variety of display design questions. Initially, different task combinations would be simultaneously presented to the peripheral and central fields in order to assess the degree to which the visual subsystems shared common processing resources. These experiments would compare dual task performance and mutual task interference when the central and peripheral fields are required to perform identical tasks and when they are required to perform tasks with separate central processing and response resources. A crucial condition would be the comparison of two tasks performed by central vision alone vs. the same two tasks shared between central and peripheral vision. This comparison would provide a clear evaluation of the conditions under which peripheral vision provides true additional processing capacity to the pilot or operator.

Additional dual task studies would address the issues of S-C-R compatibility and task integration. Compatibility experiments would compare the interference obtained between foveally and peripherally mediated task performances as a function of the combination of peripheral vision with specific types of central processing and response requirements. Task integration studies would explore the assignment of simultaneous tasks to the two subsystems in order to optimize total performance.

## SUMMARY

The central thesis of this brief chapter is that the ultimate measure of a sensory system is the quality of performance that it exhibits when acting in concert with other information processing mechanisms to complete a specific task. It follows from this thesis that answers to questions about the optimal use of peripheral vision aircraft displays must be derived from an understanding of the functional performance capabilities of peripheral vision rather than its psychophysical characteristics.

Up to the present, the design of peripheral vision displays has been based on knowledge of the natural role that this sensory subsystem plays in mediating spatial behavior. While this approach has led to some successful applications in the cockpit, it fails to consider the potential capabilities of peripheral vision in mediating other pilot performances. The essential question that has not been answered by previous research is whether or not peripheral vision can provide an additionally "free" input channel to the pilot, thereby relieving the demands currently placed on the foveal system.

In order to address this question, a human performance model is presented which focuses on the nature of human information processing capacity. The model offers a methodology to test the performance capabilities of peripheral vision, and to assess the potential suitability of various task categories for assignments to this sensory subsystem. A research plan based on the model is outlined in the final section of this chapter. The purpose of this research is to develop explicit design guidelines for future peripheral vision aircraft displays.

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## CHAPTER 4

### IMPROVEMENT OF THE CAPABILITIES OF THE PERIPHERAL VISUAL SYSTEM THROUGH TRAINING

Julien M. Christensen, Ph.D.

#### INTRODUCTION

The importance of good foveal vision to success as a pilot has never been questioned. General Chuck Yeager attributes much of his success as an outstanding fighter pilot to his incredibly acute vision (Yeager, 1985). We suspect that good peripheral vision may also be of importance in piloting.

The importance of peripheral vision with respect to many nonpiloting tasks is easily demonstrated. Body sway, for example, increases if one eliminates all peripheral cues, yet one can hold sway to a minimum if foveal vision is blocked. The uneasy feeling that one gets standing at the edge of a cliff or at the edge of a roof of a tall building has been attributed to the loss of peripheral cues in the immediate area. Interestingly, most people do not get this sensation inside a commercial airliner where, of course, there are bountiful peripheral cues--numerous "perceptual anchors," so to speak.

As emphasized elsewhere in this report and throughout the literature (cf. Liebowitz, H. W., et al., 1982 and Liebowitz, H. W., et al., 1983), the traditional role of the peripheral or ambient system has been detection. Once something is detected in the peripheral visual field, the traditional view is that it is passed with little, if any, pre-processing (at least at the cortical level) to the primary or foveal (focal) system for identification and a decision regarding the need for detailed examination.

Reflection regarding the functions of the visual system suggests that in the past the load on the visual system was such that this process of referring most of the sensory information received in the peripheral system to the foveal system generally did not overload the latter. Thus, there was essentially no requirement for the peripheral system to serve any function other than that of detection and as an element in some of man's autonomic subsystems.

There is some evidence that individuals engaged in certain jobs or who excel in certain avocations have form fields that are larger than average. For example, Christensen (1950) found in one experiment that the individual with the largest form field was an accomplished pianist. Kraft (personal communication) has found that, almost without exception, individuals engaged in sports that require a general awareness of a broad visual field tend to have relatively large form fields. Whether this (i.e., a large form field) is inherited or acquired is not known.

Kraft and Williams (1985) report that athletes were significantly better at detecting direction of motion in the peripheral field than were nonathletes. Reardon of TransWorld Airlines (TWA) (personal communication) reports that senior pilots have significantly larger form fields than their nonpilot controls. It would be of considerable interest to measure the form fields of a sample of fighter pilots and to determine whether or not there is any relationship between skill as a fighter pilot and size of visual form field. If such a relationship were to be found, the implications for attempts to expand the functional form field are obvious. It is important, then, to learn (1) whether or not Hartman's "top 20 percent" of fighter pilots tend to have relatively large form fields and, if they do, (2) whether or not the visual form fields of the rest of the population of fighter pilots can be usefully expanded through appropriate training procedures. If a positive answer is found to both of these points, then a program aimed at expanding visual form fields should make a positive contribution to Hartman's program to raise the skill level of all fighter pilots to the 99th percentile to excellence.

#### POSSIBLE ADDITIONAL ROLES FOR THE PERIPHERAL SYSTEM

With the advent of increasingly complex systems and the inevitable increase in workload, most of which falls on the visual system, it seems sensible to ask whether or not the peripheral system might not assume some of the functions that in the past have been carried out by the foveal system. Possible roles that come to mind include monitoring (of which the Malcolm Horizon is a prime example); processing of selected forms or shapes (perhaps, again, in essentially a monitoring mode with forms and shapes designed with the acuity limitations of the peripheral system in mind); and a confirmatory role in which the peripheral system is used to validate the perceptions of the focal system.

The assumption by the peripheral system of some of the traditional functions of the foveal system depends on the affirmative answers to several questions. For example, are there neural pathways to the cortex from the peripheral system and are they adequate to support significant processing? As indicated in Chapter 2 of this report, pathways seem to be present. The potential capability that they might support processing is not known.

Second, does the cortical representation of the peripheral system occupy the same cortical resources as the foveal system? If so, there would seem to be little advantage to having what traditionally have been foveal functions assumed by the peripheral system; i.e., the overload might be central and not sensorial. Preliminary anatomical considerations appear to argue against such interference, but Chapter 3 proposes a model and experimental plan for testing this definitely.

Thirdly, to what extent can the peripheral system be trained to perform functions such as those mentioned previously? This last question is the topic with which most of the rest of this chapter is concerned. Research is needed, then, not only to establish and evaluate absolute and relative thresholds for

this secondary "form" system but also to establish how amenable it is to functional development through training. The thresholds will provide guidance to those human engineering specialists responsible for working with engineers on the design of displays for the peripheral system, and the concept is in line with Malcolm's suggestions that more attention be given to the possibility of having "housekeeping" tasks handled at the subconscious level (Malcolm, 1983).

#### POSSIBLE ADVERSE EFFECTS OF FORM FIELD EXPANSION

Are there any possible adverse effects associated with expansion of the visual form field? We think not, but perhaps certain possibilities should be considered. While most subjects report this "expanded awareness" at least interesting, some subjects have suggested that it is also distracting or even disturbing. (These feelings, where they exist, probably disappear once the individual has learned to integrate this improvement in the ambient visual system into the overall visual perceptual system.)

Perhaps of greater concern would be any possible alteration in the nature of the interactions between the vestibular system and the visual system. To quote directly from the excellent writings of Leibowitz et al. (1982), "It should be noted that not only is combined stimulation from the vestibular and visual senses necessary for accurate orientation, but also that the sensory information must correspond with previous experience." And later in the same article, "In everyday life acceleration of the head produces both forces which activate the vestibular system and motion of the retinal images of surrounding objects. However, acceleration in an aircraft, when outside detail is not visible, carries the visual surroundings along with the head. As a consequence, forces on the vestibular system are no longer matched by retinal image motions of the surrounding. This represents a mismatch or conflict in comparison with previous experience which the pilot must 'override' in order to maintain correct orientation." (op. cit.) Whether or not an expanded ambient form field will provide more for the pilot to "override" is an interesting question. If we adapt the ambient system to a broader field, then will environments (e.g., closed cockpits) that narrow this field tend to induce disorientation and/or nausea? Disorientation and motion sickness are relatively rare among pilots but, nevertheless, are very severe problems when they do occur. We note in passing that the Malcolm Horizon might actually enhance the interaction between peripheral visual cues and vestibular cues. It would be interesting to compare the areas of the ambient visual form field of pilots, and especially astronauts, with any instances of disorientation and/or nausea.

Finally, if an expanded visual form field results in any untoward effects, the experience of the writer and another investigator in the field suggests that without periodic refreshment the form field tends to "shrink" to its original area (Kraft, personal communication). Thus, adverse effects, if any, appear at this time to be reversible.

## POSSIBLE INTERACTIONS WITH STRESS

Generally, pilots want a broader field of view (cf. Martin, 1983), although the remarkable accomplishment of Lindberg in 1929 shows what exceptional pilots can do with a limited field of view. Field of view has been studied systematically by Roscoe and his associates (1966) whose subjects after limited practice were taking off and landing safely by periscope.

Fighter pilots conduct their real business in very stressful environments. Several investigators (cf. Buisill, 1958, Williams, 1985, Mockworth, 1965, 1976) suggest that stress will cause the visual field to narrow ("tunnel"; "funnel"). This result would seem to suggest that all critical visual functions should be assigned to the foveal system. However, as Haber (1982) suggests, it is not clear from studies of this type whether or not processing of optic flow information is degraded as well as processing of information relating to identification ("where" and "what"). We would hope that processing of optic flow information is essentially independent of the processing of identification information. However, a study by Houtmans and Sanders of the Institute for Perception (1984) suggests that their results support "... the controlled processing hypothesis, at least with regard to the acquisition of content information for the periphery." (Unfortunately, only an abstract of this study was available when this was written so that details of the experiment could not be evaluated. We would hope, but have no evidence, that any expanded capabilities of the ambient system would, with practice, be handled pretty much automatically as is present "where" information.)

O'Donnell's analysis (Chapter 2) suggests that independent processing of peripheral and foveal stimulation is at least possible. It would be encouraging to be assured that processing of any peripheral stimulation (form or flow) is carried on independently of the processing of foveal stimulation. Other investigators (cf. McGrath, 1960) suggest that subjects may perform better under some stress conditions (increased information load) because of the general increase in arousal level. A study by Liebowitz and Appello (1969) would seem to support this position.

Bartz's (1976) results suggest that arousal and funneling may be operating simultaneously. He suggests that under mild stress (greater arousal) only slight funneling may occur. We interpret this result to mean that "housekeeping" sorts of tasks and confirmatory tasks might safely be relegated to the peripheral system. Doing so might, in fact, reduce the stress on the pilot, particularly after many of these tasks had become essentially automatic.

We take heart from the suggestion of Liebowitz et al. (1982) that "... under some kinds of stress, narrowing may be limited to focal processing while ambient functions remain (sic) intact." They go on to point out that "psychological" stressors (e.g., fear) may result in the narrowing of focal vision only, while "physical" stressors (e.g., hypoxia, acceleration, etc.), because of restricted blood flow and other physical effects, may narrow both foveal and peripheral vision. The first type of stress (psychological) suggests that it should be advantageous to assign more tasks (perhaps "housekeeping" tasks)

to the ambient system. The second type of stress (physical) suggests that we must continue to improve our devices, procedures, etc., for protecting pilots from the effects of physical stressors.

It is important to emphasize that we do not consider the peripheral system to be the equal of the foveal system for most, if not all, visual functions. It is realized that both absolute and relative thresholds increase for acuity as one goes toward the periphery. Larger and larger refractive corrections are required in the periphery. Images may appear slightly larger in the periphery than in the foveal area because they appear fuzzier. The Stiles-Crawford effect is different (the rods do not seem to possess the same directional sensitivity as the cones). Contrast becomes a much more important cue than color. Actual velocities and their derivatives are not judged as well (probably because position is not defined as accurately in the periphery).

However, the comments just mentioned miss the point. Our hope is that through training and design of displays that take account of the differences between foveal and peripheral vision, the peripheral system may contribute much more than it currently contributes to pilot effectiveness, not only as a primary receiver of information but also as a confirmatory medium. As to a primary source, Rogers (1972) suggests, for example, that use of the phi-phenomenon in the periphery should result in an extremely compelling display. Some of these might help the pilot perform better in his unusually stressful environment.

#### DEFINITION AND GENERAL NATURE OF THE VISUAL FORM FIELD

Renshaw (1945) defined the visual form field as "... the solid angle within and beyond the region of the anatomical macula in which an observer is able to see shapes." Later, Renshaw (1946) developed a more specific operational definition which defined the visual form field as "the solid subtended angle in which 36-point (9 mm) century bold digits can be identified correctly five out of five trials under nine foot-candles of illumination at a focal distance of 26 inches" (Christensen, 1950).

The two methods most widely used to expand the visual form field are tachistoscopic and perimetric. The tachistoscopic method can be traced back at least to Kroh, who in 1922 measured the ability of children to perceive longer and longer lists of words presented tachistoscopically (Kroh, 1922).

In 1931, Seward showed that perception of single letters presented behind a ground glass screen could be improved with practice (Seward, 1931). (The writer has informally observed a similar result by defocusing the lens on a shutter.)

Aveling (1932[1]), writing in the British Journal of Psychology, found that the subject's attention was attracted to the unusual portion of the field (e.g., to the one letter of a group which is reversed). In a second study (Aveling, 1932[2]), the same investigator examined pre-exposure set of the



subjects and found that if a subject were set to see a certain symbol, he saw it regardless of its position in the field. There was, however, a corresponding loss in the perception of other materials in the field. It is realized that the findings of investigators Seward and Averling (two examples from a host of possibilities) relate primarily to only the foveal system. However, once it is established that performance on some visual functions can be improved by appropriate training, then it would appear fruitful to examine functions in the primary system that have been improved by training as one means of guiding research efforts on the peripheral system.

#### EARLY INVESTIGATORY WORK

Much of the original investigatory work on form fields comes from the laboratory of Renshaw. Renshaw's original method consisted of training individuals to read increasingly long series of digits at exposures of the order of 1/50 to 1/100 sec. The following are some of the conclusions that were drawn from this work by Renshaw and his students (Banner [1940], Renshaw [1945(2), 1946], Schwarzbek [1935], Knight [1936]):

1. Expansion of the visual form field in the horizontal dimension tends to expand it in all dimensions. (This strongly suggests, of course, that we are dealing with a central, rather than a peripheral, phenomenon.)

2. The improvement (i.e., expansion) is nonspecific; i.e., individuals trained on one type of stimulus material improved their performance on quite different types of materials. For example, individuals trained on digits were able to read faster and to identify aircraft silhouettes more accurately. (Note: The generality of this transfer function is one of the key points of contention in this field.)

3. An entirely different set of perceptual functions is employed by the expert as compared to the novice. Knight (1936) contended that with the advent of virtuosity, imagery and visual processing tend to disappear and the emphasis shifts to the motor side, bearing out the insistent contention of Purdy (1935[2], 1936[2]) with respect to the significance of motor involvement in perception.

4. (See also 3.) As the level of virtuosity increases, the physical stimulus plays a greatly reduced role, serving only to trigger off the perceptual process. Such factors as position, size, brightness, etc., become increasingly less important. This conclusion would appear to agree with the British psychologist's position that any percept is essentially the result of a construction process, dependent for its nature on a relatively small amount of immediate stimulation and a relatively large amount of material extracted from past experiences stored in memory (Bartlett, 1934).

5. Factors such as subject set, grouping, and so on affect the results. These factors may change in relative importance and degree as greater expertise is acquired.

6. Once a perceiver has reached a high level of proficiency, he sees more accurately with short exposures of the material than with long exposures. Renshaw and his students interpret this as evidence of the importance of the motor side of the perceptual process.

7. Finally, Renshaw and his students found that virtually anyone without a serious limiting physical disorder could improve his perceptual abilities with practice on tachistoscopically presented materials.

Low (1946) was another early investigator who found that training could improve virtually all peripheral functions. His impressive results are worth summarizing.

1. After training, it was necessary to stimulate an area only one-eleventh the size necessary before training. Low interprets this to mean that after training the observer could perceive eleven times as much detail.

2. The critical issue of transfer to other types of tasks was answered with a resounding "yes" by Low. He claimed positive transfer to (a) retinal areas not worked by his training technique (supporting the writer's view that we are dealing with a central, not a peripheral, phenomenon), (b) night visual acuity, (c) more rapid recognition of simple forms, (d) positive transfer to unfamiliar objects, (e) positive transfer to retinal areas 90 degrees from the line of vision, (f) positive transfer to nonperimetric visual acuity, and (g) positive transfer to conditions outside the laboratory. To quote Low, "In no case was there doubt that the trained subjects excelled untrained ones in situations involving acuity of peripheral visual perception" (op. cit.).

Why the results of experiments by the writer and Crannell were not nearly as convincing as were Low's results is not immediately apparent. Perhaps differences in training techniques were responsible.

As hinted at earlier, form field expansion and the methods used to achieve it have been contentious. Gibson (1944) implies that tachistoscopic training is essentially a memory process, primarily dependent on frequency of impression.

Based on the results of an experiment conducted in graduate school, I concluded that form fields could be increased by either tachistoscopic or perimetric techniques (the smaller number of subjects did not allow a comparison of the relative effectiveness of the two techniques) and that those with expanded form fields did significantly better check reading a bank of 16 (4 by 4) aircraft-type dials. The results of the experiment were even more impressive when analysis disclosed that control and experimental subjects performed equally on the central 4 dials of the 16-dial matrix and that the superior scores of the experimental group were due entirely to their performance on the 12 dials that surrounded the central four (Christensen, 1950).

This experiment led to a series of studies by Crannell and Christensen (refs. 1954, 1955, 1956) which showed several things:

1. Training on selected stimuli (digits in this case) did result in an ability to identify these same stimuli farther and farther out in the periphery. Expressed another way, the form fields of the subjects were significantly expanded with respect to recognition of the stimuli on which they were trained.

2. While both tachistoscopic and perimetric training resulted in expanded form fields with respect to the stimuli used in the training sessions, the perimetric method was more effective for the same amount of training time. The average form field of the perimetric group increased more than three-fold after approximately 20 hr of training.

3. Transfer of training to classes of stimuli quite different than those on which the subjects were trained was discouraging, with one exception. These tests included (a) check reading a panel of simulated aircraft dials, (b) reading speed and accuracy, (c) ability to identify forms completely different from those on which the subjects were trained, and (d) Landolt rings. There was persistent evidence of some positive transfer to the Landolt ring task (i.e., improvement in the subject's ability to identify the orientation of the ring by specifying the location of its discontinuity). In addition, in the 1955 experiments, although individual "t" tests were generally not significant, examination of pretest and posttest means suggests that an effect might be present.

4. The increased size of form field not only was greater for groups given perimetric training than for groups given tachistoscopic training, but also was achieved more quickly.

5. The acquisition curves for increase in size of form field as measured in terms of numeral identification had not produced an asymptotic pattern after approximately 20 hr of training.

6. Significant correlations were found between the initial size of form fields and their size after approximately 20 hr of training. For the maximum fields, this correlation was +0.80; for the minimum fields, this correlation was +0.64. ("Maximum" is defined as that area which was covered by the form fields of both eyes, taking the widest measure of each eye independently; "minimum" is defined as that area in which the form fields of the two eyes overlap.)

The authors interpreted the improvement on the materials used in training as due to the subjects learning to respond to reduced cues (an interpretation of these sorts of events that is favored by Gibson, 1953); thus, for example, one learns to distinguish a "1" from a "7" by simply observing that the "7" has a horizontal component that is absent in the "1". The similarity between Landolt rings and digits did little to dissuade the authors with respect to their "reduced cues" interpretation of the small but persistent positive transfer effects from digits to Landolt rings. The "reduced cues" interpretation was strengthened when, instead of numerals, subjects were trained on a wide variety of shapes (Roman numerals, letters of the alphabet, geometric shapes, etc.) and then found that there was evidence ( $p < 0.10$  for one-tailed "t" test) of transfer not to Landolt rings but shapes. (Progress during training was also slower than on previous experiments on which only digits were used as stimulus materials but there was progress. At that time, the writers interpreted this as requiring the subjects longer to learn the greater variety of reduced cues presented in the experiment.)

No research was uncovered that dealt directly with the establishment of absolute and differential thresholds for the peripheral system when it comes to judging velocity and its derivatives. Gottsdanker (1952), relying on foveal

research, suggests that individuals infer acceleration by comparing velocities observed over two independent time periods. This finding was confirmed by Gottsdanker, Frick, and Lockard (1961).

More research is clearly needed in this area. The functions should be fairly independent of form and fairly amenable to improvement through training. Some tracking studies, using the foveal system, suggest that going to the second derivative of velocity probably would not be too profitable, although this might very well change with more practice. Nevertheless, the development of increased capability to estimate velocity and at least detect positive and negative acceleration in the periphery might have significant value as another resource for handling "housekeeping" functions.

In summary, what can be concluded from these earlier studies that relates to aircrew performance?

There is no doubt that the visual form field can be expanded. The only question is, and it is a fundamental question, does the increase in form field represent a generalized improvement or does it simply mean that the trainees learn to differentiate among stimuli on which they are trained by attending to subtle differences in those specific stimuli that previous tasks had not required; i.e., do they learn to respond to reduced cues? Or do they learn to respond in a different manner to any and all peripheral stimuli--to notice detail, for example, that had not been required of them in their customary perceptions? Of course, the answer may include both interpretations; i.e., there may be a generalized increase in peripheral capability, perhaps attentional in nature, abetted by a familiarity component. Because of the rapid acquisition of an increased form field, we rule out the possibility of additional neural pathways being established.

#### THE CASE FOR RENEWED INTEREST

Several events have occurred which suggest not only that more attention should be given to the fundamental characteristics of the ambient field but also that the possibilities of improvement through training should be further explored. For example, Kerr (1971) found visual acuity at 10, 20, and 30 degrees from the fovea to be two to four times higher than those reported previously. (Her methodology could well serve as a model for anyone wanting to take threshold measurements in the ambient field.)

Menger and Thurmond (1970) confirmed and extended previous work regarding the perception of forms in the periphery. They found identification of metric polygons not only superior to the identification of metric histoforms near the fovea, as Thurmond (1969) and Thurmond and Hancock (1969) had found, but also superior throughout the periphery. (Metric polygons are irregular closed shapes; metric histograms are relatively simple shapes that appear as solid bar graphs against a white background and black outlined bar graphs with white surfaces that are distinguished from the background by only the contour.)

Menger and Thurmond (1970) also confirmed previous work by Thurmond and Hancock (1969) by showing that identification of six-element figures viewed centrally is generally better on outlined than on solid-surfaced shapes. As many other investigators have found, they also found that while performance progressively deteriorates as stimuli are removed from the foveal area, shapes could be identified much farther in the periphery than previous research had suggested. This finding confirms the work of the writer and Crannell (although it says nothing about transfer of training) and would be expected in light of Kerr's work (Kerr, 1971).

Menger and Thurmond (1970) also found that beyond 20 degrees from the foveal identification was better for solid-surfaced forms than for outlined forms, and, finally, that performance on both solid and outlined forms is a decreasing linear function of the degree of removal from the foveal. In general, their findings are consistent with the distribution of retinal elements. They do not address the possibility of improving performance through training. However, the fact that shape is the most significant dimension out to 50 degrees, whereas beyond 50 degrees the surface (outlined or solid) of a form is more important, may have significance for human factors engineers who advise design engineers.

Scanning behavior becomes more important as the number and diversity of aircrew tasks increases. In excellent papers by Spady and Harris (1983) and by Harris and Spady (1985), scanning behavior is considered as a subconscious or an automatic conditioned activity. This, we feel, is the sort of activity that should be investigated with respect to the possibility of assigning it to the ambient system. The capabilities of the ambient system in this area need very much to be determined; if found to be substantial, they offer considerable promise for relieving the foveal system of some of its most persistent and insistent workload activities.

We take mild exception to one comment in the Harris-Spady paper. They say (page 2), "Since scanning is subconscious, pilots are poor judges of what they look at. As a result, many myths on scanning have been passed around such as 'I look between the attitude indicator and directional gyro, defocus, and take everything in peripherally.'" And later in the same paragraph, "I never look at the altimeter, but get altitude peripherally." It is not outside the realm of possibility that the pilots are correct; their observations are not imaginary, but rather represent what pilots have learned to do, independent of formal instruction. We should address the issue from the point of view of determining the capabilities of the peripheral system with respect to the scanning requirements of various pilot tasks.

In another paper, Spady, Harris and Comstock (1983) show, among other things, that scanning behavior in flight is significantly different from scanning behavior in a simulator. This finding clearly has implications for the design of simulators and simulator training programs.

Based on the results of their oculometer studies, Harris and Christhilf (1980) were able to classify pilot's instruments into three categories. Type "O" included only the attitude indicator. Spady (1978) had found that, at best, during instrument landing system (ILS) approaches, fixations were generally made to only one other instrument before returning to the attitude indicator. (Malcolm appears to have started at the right place with his "horizon" if his intention was to relieve foveal vision!) Type "I" instruments included digital altitude, directional gyro, course deviation indicator, and the glide slope/localizer indicator. Type "II" instruments included air-speed, engine speed, turn and bank, and vertical speed. Studies need to be performed to determine which of the earlier results under certain conditions can be handed off to the peripheral system, such as Malcolm has done for attitude. (We emphasize again that if this transfer can be done successfully, it will require design of instruments that take into account the limitations of the peripheral system compared to the foveal system.)

The Harris team has also addressed the issue of pilot workload, concluding that scanning behavior may be a useful tool for assessing not only level of skill but also level of workload (Harris, et al., 1982). If we ever get to the point of being able systematically to assign some responsibilities to the peripheral and some to the foveal system, it will be very helpful to have available reliable, valid, sensitive measures of workload.

Johnston (1965) investigated the relationship between size of visual field and time required to locate targets on static displays. She found an inverse relationship between size of visual field and time (i.e., people with larger fields found targets in less time). In a later study, the same investigator found that far-vision search performance could not be predicted from near-vision acuity (Johnston, 1967).

A study very relevant to the present discussion was conducted by Leachtenauer (1978) who found correlations from 0.62 to 0.92 between field size and search performance. He also concludes, however, that "Whether or not peripheral field size can be increased through training remains in question." (Comment: As just mentioned, the earlier work of the writer and Crannell demonstrated unequivocally that the size of the peripheral form field can be increased through training; the question that demands further attention, however, [and an important one it is] is whether or not this acquired skill transfers to classes of stimuli different from those used in training.) Leachtenauer concludes that peripheral field size could profitably be used as a selection tool and that "field expansion training, when administered in conjunction with other types of search-related training, can provide comparable improvements in search performance."

Studies by Goolhasian and Bunt (1973) of the Institute for Perception are relevant to this discussion. After a period of training with one horizontally moving light in the region of 15 to 30 degrees, the peripheral system was able to handle information in this region with accuracy equal to that of the foveal system. This was true, however, only when the perceptual task was a relatively simple one.

A second experiment, however, confirmed the finding that only limited information can be handled in the periphery and showed that this factor, complexity, is far more important than the area of the periphery in which the stimuli appear. Training close to the fovea was shown to be effective with attention or practice, while effective training in the peripheral regions demanded both attention and practice.

These findings and urgings by friends convinced the writer that he should reexamine the data that were available in the three reports by him and Crannell<sup>1</sup>. Briggs (personal communication) pointed out that it would be quite reasonable to use a one-tailed test for interpreting "t" ratios in these experiments since it would hardly be expected that training would shrink the visual form field.

The results of this reexamination are shown in Tables 1 through 4<sup>2</sup>. Table 1 suggests that there is some evidence (compelling for the experimental group with the most training) that training on numerals did transfer positively to a dial check reading task. Note, also, that although some of the mean differences between the control group and the experimental group were not significant, nevertheless, in all four cases the means of the experimental groups exceeded the mean of the control group. The odds are only 1 in 16 (i.e.,  $[1/2]^4$ ) that this circumstance could be due to chance factors alone.

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<sup>1</sup>The writer is indebted to Dr. S. James Briggs who urged him to reexamine some of his early work.

<sup>2</sup>The writer is indebted to Mr. Mark Crabtree who performed much of the following analysis.

TABLE 1. RESULTS OF PERIMETRIC TRAINING IN TERMS OF A DIAL CHECKING CRITERION\*

<u>Group</u>	<u>N</u>	<u>X</u>	<u>S.D.</u>
Control (C)	10	15.7	6.63
E-1 (5 hr)**	10	18.4	6.47
E-2 (10 hr)	10	20.9	7.32
E-3 (15 hr)	10	18.9	5.34
E-4 (20 hr)	10	23.5	6.73

	<u>t</u>	<u>d/f</u>	<u>p (one-tailed test)</u>
C vs. E-1	0.92	18	N.S.
E-2	1.66	18	.10
E-3	1.19	18	N.S.
E-4	2.60	18	.01

\* Source: Cransall and Christensen (1955)

\*\* The number of hours of training received by each experimental group

TABLE 2. RESULTS OF PERIMETRIC TRAINING IN TERMS OF A TRACKING CRITERION\*

<u>Group</u>	<u>N</u>	<u>X</u>	<u>S.D.</u>
Control (C)	10	7.7	2.54
E-1 (5 hr)**	10	8.3	4.55
E-2 (10 hr)	10	8.1	2.73
E-3 (15 hr)	10	8.8	2.57
E-4 (20 hr)	10	9.6	2.50

	<u>t</u>	<u>d/f</u>	<u>p (one-tailed test)</u>
C vs. E-1	0.36	18	N.S.
E-2	0.34	18	N.S.
E-3	0.96	18	N.S.
E-4	1.68	18	.10

\* Source: See footnote, Table 1.

\*\* Hours: See footnote, Table 1.



TABLE 3. RESULTS OF PERIMETRIC TRAINING IN TERMS OF LANDOLT RING CRITERION\*

<u>Group</u>	<u>N</u>	<u>X</u>	<u>S.D.</u>
Control (C)	10	25.5	9.38
E-1 (5 hr)**	10	49.0	13.5
E-2 (10 hr)	10	47.0	13.94
E-3 (15 hr)	10	28.5	10.16
E-4 (20 hr)	10	32.1	9.78

	<u>t</u>	<u>d/f</u>	<u>p (one-tailed test)</u>
C vs. E-1	4.33	18	.01
E-2	3.67	18	.01
E-3	0.69	18	N.S.
E-4	1.54	18	.10

\* Source: See footnote, Table 1.

\*\* Hours: See footnote, Table 1.

TABLE 4. RESULTS OF PERIMETRIC TRAINING IN TERMS OF FORM CRITERION\*

<u>Group</u>	<u>N</u>	<u>X</u>	<u>S.D.</u>
Control (C)	10	58.3	16.34
E-1 (5 hr)**	10	66.1	23.26
E-2 (10 hr)	10	68.3	15.25
E-3 (15 hr)	10	64.6	14.36
E-4 (20 hr)	10	61.2	15.96

	<u>t</u>	<u>d/f</u>	<u>p (one-tailed test)</u>
C vs. E-1	0.36	18	N.S.
E-2	1.41	18	.10
E-3	0.92	18	N.S.
E-4	0.40	18	N.S.

\* Source: See footnote, Table 1.

\*\* Hours: See footnote, Table 1.

Table 2 discloses that one experimental group (again the one with the most training) did significantly better ( $p < .10$ ) on a visual tracking task than did the control group. Note again, however, that in all four cases the means of the experimental groups exceeded the means of the control group, although admittedly by very little for at least two of the four groups.

Table 3 confirms what was pointed out in the original reports; i.e., there is substantial evidence to support a contention of positive transfer from training on numerals to performance on Landolt rings.

The results shown in Table 4 hint at the possibility of some transfer from training on numerals to identification of forms of a wide variety (including, incidentally, a few numerals). This finding is crucial and needs replication. Note again, however, that the means for each of the experimental groups exceeded the mean for the control group.

What is one to conclude from all of this? First, there is no doubt whatsoever that peripheral acuity and identification can be improved in terms of the stimuli on which the subjects are trained. (This is not a trivial finding, but it does suggest that until more is known trainers would be well-advised to maximize the similarity between training materials and materials expected to be encountered on the job.)

Second, there appears to be some transfer from training on numerals to other types of materials. However, we must restate that the strongest evidence was with respect to Landolt rings whose physical characteristics are quite similar to numerals. We are not yet ready completely to abandon the "reduced-cues" hypothesis; however, we would be delighted to find that it is only one of two or three contributing factors.

Third, what is needed is a series of experiments in which such dimensions as size, orientation, shape or form (including filling, etc.) are systematically varied so that one could specify which dimensions are critical to the achievement of positive transfer effects. Once this is done, the practitioner could then examine the characteristics of the criterion stimuli and choose for his training program stimuli with similar dimensional characteristics. As mentioned previously, until this is better understood, practitioners would be well-advised to use stimulus materials that are as similar as possible to those found in the criterion tasks.

#### SUMMARY

There is no doubt that the visual form field can be expanded if the criterion materials are the same as the training materials. In addition, at least one investigator (Low) has obtained substantial positive transfer effects to stimuli quite different from the training stimuli. Others have obtained results that suggest positive transfer although the stimulus characteristics that effect this have not been defined.

A functionally useful expanded form field immediately suggests numerous functions that should be investigated to take maximum advantage of this capability. Considerable investigatory work would be required before optimal assignments to the two visual fields could be specified. In addition, optimal training procedures, equipment, and materials have yet to be defined.

These and other issues need attention. Even if it should turn out that the improvement that can be effected is less than dramatic, it should be given consideration. Any technique, capability, or piece of equipment that might give a pilot even a slight advantage over his adversary merits careful consideration.

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## CHAPTER 5

### THE HISTORY OF PERIPHERAL VISION DISPLAYS

Gary Williamson

#### HISTORY

The concept of utilizing the peripheral visual system as an input source for critical flight information has received limited attention. However, past research has led to the development of several different aircraft displays targeted at using this channel (Assenhein, 1983; Brown, 1961; Ener, 1974; Fenwick, 1963; Hasbrook, 1968; Hasbrook and Young, 1968; Hasbrook and Young, 1968; Hasbrook, 1968; Knots and Gawron, 1984; Malcolm, 1984; Malcolm, Money and Anderson, no date; McNaughton, 1983; Nims, 1983; Swank, Bermudez, Smith and Harris, 1978; Vallerie, 1968; Reprint from Aerospace, 1982; Garrett, 1984). Only two of these displays have been made commercially available; i.e., the Peripheral Command Indicator (PCI) and the Peripheral Vision Horizon Display (PVHD). Most of the peripheral vision displays developed to date present primarily attitude or heading information to the pilot. This approach is understandable when one considers the importance of such information during certain flight maneuvers. According to one study on the visual scanning behavior of pilots while performing climbs, holding patterns, and instrument approaches, pilots spend approximately 45 percent to 55 percent of their time fixating on the attitude indicator (ADI) (Harris and Christhlf, 1980).

Of all the peripheral displays investigated, the one that appears to have the most promise is the Malcolm Horizon (or Peripheral Vision Horizon Display (PVHD) - Garrett Mfg.). The display consists of an artificial horizon line (red laser) which is projected onto the instrument panel and extends well into the pilot's periphery. The artificial horizon simply duplicates pitch and roll motions of the real horizon.

What makes this display so promising? First of all, it focuses on solving a problem that has been troubling aviators since World War II--spatial disorientation refers to "situations in flight in which the pilot's perception of the attitude, position, or motion of his aircraft or other objects in space is nonveridical (i.e., perception differs from physical events)" (Clark, 1971). According to statistics, disorientation is believed responsible for an estimated 15 percent of all fatal aircraft accidents dating back to World War II (Malcolm, 1984). Interestingly, this figure has remained constant despite the advent of advanced aircraft with increased capabilities and despite efforts to optimize the pilot-cockpit interface. Although the PVHD presents no more information than that provided by a conventional ADI, it extends well into the periphery allowing the pilot to attend foveally to other instruments while

simultaneously absorbing critical attitude information through the peripheral visual field. This increase in peripheral stimulations, it appears, tends to improve the pilot's situational awareness.

Based on a survey of 2000 naval aviators, the factor listed as contributing most to episodes of disorientation was poor visibility (Tyler, 1970). The study also found that 72.5 percent of the pilots surveyed experienced this phenomenon when under Instrument Flight Rules (IFR). Malcolm (1984) states that "orientation comes primarily from vision, then from the organs of balance (vestibular system) then the proprioceptive and the kinesthetic senses." Malcolm proceeds to demonstrate how the peripheral visual system, in contrast to the central visual system, is primarily responsible for cueing the human to proper orientation of the body.

The role of the vestibular system as a contributing factor has undergone extensive investigation; in fact, many researchers believe this system to be the primary sensory mechanism involved (Bauer, 1930; Clark, 1970; Clark, 1971; Howard and Templeton, 1966; Kato, 1970; Kato, 1968). This research has led to discovery of a phenomenon known as the Coriolis effect (Geldard, 1972; Liebowitz, Post, Brandt, and Dichgans, 1982; Peters, 1969). "This occurs whenever one set of semicircular canals has adjusted to a constant angular velocity--the endolymph has caught up with the canal walls, so to speak--and a new head motion in a different geometrical plane is made. Then there occurs at one and the same time a deceleration in the canals originally stimulated and a new acceleration in a different set of canals. The net result of these complex changes is that motion comes to be perceived in a direction in which real motion is not occurring" (Geldard, 1972). If a pilot were to experience such an effect in a high-speed aircraft during a critical flight maneuver and at low altitude, one can imagine the consequences.

The PVHD offers another advantage in that it is more visible than conventional instruments during turbulence and vibration (Malcolm, Money and Anderson, no date). However, the PVHD does have one major drawback. Although the system was designed with some degree of flexibility to allow for installation in cockpits of varying configurations, one study concluded that "as a result of compromises for the sake of installation, a less than desirable display area might seem necessary in order to use the PVHD" (Nims, no date). Manufacturers of the display are hoping to solve this problem on future PVHD designs through utilization of holography. A modification of this nature would (1) enable the artificial horizon to be projected in space rather than on the instrument panel; (2) eliminate the possibility of the laser beam straying outside the cockpit where it may be traced by enemy aircraft; and (3) possibly enable designers to "present to the pilot a view similar, if not identical, to the true horizon; i.e., an interface between two areas, sky or ground, blue or brown, or even to present the complete 3D picture of an airport runway, regardless of whether the airport is in fact visible" (Assenhein, 1983).

Malcolm (1984) points out that "the major task of teaching a pilot to fly, in conditions where he cannot see outside is to instill in him that he must ignore his senses and stick to what the instruments tell him." With this



in mind it seems only logical that one of the major goals of future aircraft display designers should be to alleviate the potential for pilot error due to conflicting sensory interactions through design of unique and innovative displays.

As pointed out earlier, several aircraft displays have been developed which target the peripheral visual system as the input source for critical/confirmatory flight information. The following matrix includes eight different peripheral vision displays developed to date. Each display is discussed in terms of physical characteristics (i.e., appearance, size, location, orientation, etc.), information conveyed (i.e., pitch, roll, heading, etc.), and test results. Examination of the matrix suggests that, while much more research needs to be done, the idea of designing displays that can be used effectively by the peripheral system appears to be one worth pursuing.

# PERIPHERAL VISION DISPLAY MATRIX

## Displays

Peripheral Vision Horizon Display  
(PVD) or Helium Horizon  
(References: 1,16,19,19,20,21,26,27)

Peripheral Command Indicator (PCI)  
(References: 7,25)

Para-Visual Director (PVD)  
(References: 3,25)

Streaming Light Display  
(References: 3,25)

Flashing Light Display  
(References: 3, 25)

## Physical Characteristics/ Information Conveyed

The three-component system consists of a central processing unit (CPU), projection unit, and display control panel. The projector utilizes a 3.0 mW HeNe laser to produce a red artificial horizon line across the instrument panel (Fig. 2).

The projector is positioned such that it presents a parallel corrected image to the pilot. Corrections are also made to eliminate irregularities in the artificial horizon line due to configuration of the instrument panel. Specific location of each component and corresponding adjustments vary among the different types of aircraft.

The artificial horizon line duplicates pitch and roll motions of the real horizon. The display control panel allows pilots to adjust the brightness of the laser beam, pitch and roll trim, and pitch scale or sensitivity (Fig. 3).

The black and white display consists of two concentric cylinders, each with a helix inscribed on it. The contrainfo is designed such that when it receives appropriate signal inputs from the aircraft's gyro platform the pattern will move in any desired direction (up, down, left, right, or any vector in between) and at any desired rate within a wide range (Fig. 4).

The display presents both pitch and roll information. The PCI is analogous to the PVD in that control inputs required of the pilot is in correspondence to the perceived motion generated by the display (i.e., "if movement is perceived in the direction left to the right of vertical the pilot must pitch up and steer slightly to the right until the display is nullified"). The rate of movement represents the magnitude of correction required.

The display is comprised of three separate components. Each component has a "barber pole-like" appearance (i.e., a black tube with a white helix painted on its surface) and is motor driven (Fig. 5).

The display presents both pitch (side display) and roll (for bank angle) (front display) information. Rotation of the cylinder produces the illusion of longitudinal motion along its axis. When the bank display shows motion either to the left or right, the pilot must bank the aircraft correspondingly until motion of the display ceases. Similarly, if the two side displays show motion either forward or backward the pilot must correspondingly push the control column forward or pull it rearward to nullify the display.

The display consists of a 21 inch row and column of neon indicator lamps, type CC31-1. Each one contains 48 lamps spaced at equal intervals. One set of lights is located beneath a central display, whereas the other is located either to the left or right of it (Fig. 6).

The horizontal lights present bearing information whereas the vertical lights present altitude information. In order to produce the streaming effect the lamps are attached to two 48-segment commutators, one lamp per segment, which are driven by variable speed/variable direction velocity motors. The control input required of the pilot corresponds to the direction of streaming (i.e., streaming movements to the left are nullified by a control movement to the left; streaming movements upward are nullified by control movement towards the pilot, etc.). Rate of streaming indicates magnitude of input required.

The display consists of four neon lamps identical in size to those used in the streaming light display above. The lamps are arranged such that there is one each above, below and to the left and right of a central display (Fig. 7). Additional testing was conducted with the display mounted to a person's visor fixed to a helmet (Fig. 8).

The lamps above and below the central display present altitude information; whereas the left and right lamps provide bearing information. A flashing light to the left indicates the need for the pilot to steer left until the display is nullified. Similarly, if the top lamp is flashing the pilot must pull back on the control column to nullify the display. Rate of flashing indicates magnitude of correction required.

## Test Results/Advantages/Disadvantages/Discussion

In this the PVD has been flight tested in some 20 different types of aircraft including several simulators (28). These include: Lockheed Jet Star; McDonnell J-42; German CP-12 Tracker; McDonnell P-4 Phantom; Sikorsky Sea King; Bell CH 133; AT-33A research aircraft; S300 A-16; B-4C; and the Canadian Armed Forces Sea King helicopter and Air Canada Boeing 747 simulators.

The PVD offers several advantages (19, 20) including:

- (1) More visible than conventional instruments during turbulence and vibration;
- (2) Visible while scanning other instruments;
- (3) Fully responsive around entire roll axis;
- (4) Reduces pilot workload;
- (5) Reduces likelihood/severity of pilot spatial disorientation; and
- (6) Improves situational awareness.

Findings based on evaluation of the PVD in the single seat night attack (SSA) A-10 (2) include:

- (1) Difficult to achieve a suitable installation in a fighter type cockpit;
- (2) As a result of compromises for the sake of installation, a loss of the desirable display area might seem necessary in order to use the PVD.

Valerio (28) conducted a study that compared the PCI with the PVD based on performance during a simulated aircraft control task. In this study, the displays were enriched (i.e., airspeed information was provided by flickering the background brightness) and enhanced (i.e., the background brightness was increased to call the operator's attention to great error ( $> \pm 50\%$ ) requiring immediate correction).

Results of the study were as follows:

- (1) "A significantly higher performance was achieved with the PCI than with the PVD";
- (2) As a result of the above finding is that the PCI demands less work of the operator due to the integration of the pitch and roll dimensions into a single display;
- (3) Performance in pitch was worse than roll regardless of the display utilized;
- (4) Both enhancement and enrichment degraded performance regardless of the display utilized;
- (5) When the operators viewed the PCI with central vision, some control-display reversals were experienced, mainly in the pitch dimension.

Brown et al. conducted a laboratory evaluation of the "barber's pole" (PB), streaming lights (SL), and flashing lights (FL) (2). Performance was based on a compensatory tracking and secondary reaction time task, were collected.

Results of the evaluation were as follows:

- (1) In correcting sudden errors the flashing lights on the helmet (FLH) yielded quicker responses than any other single display arrangement;
- (2) A combination of the FLH and a conventional ILS meter (Fig. 7) produced the quickest corrections recorded during the experiment; and
- (3) The weakest of the FLH, PVD, and SL was in presenting the magnitude of error.

# Peripheral Cue Lights (References: 10, 11, 12)

The display is comprised of two sets of lights (one green and one red light per set) both located on the pilot's control wheel, one set near the lower left corner, the other near the lower right corner. The bulbs were G.E. 6127's, 1/2" dia., 28 volt, 0.5 C. mounted in Dialco #25 101-3030 transparent color wheel of 5 in. diameter. Maximum luminance for each was 2.6 log. ft.-l. for the green bulb and 3.2 log. ft.-l. for the red. The bulbs are mounted vertically with the upper one being red (Fig. 9).

The peripheral cue lights present roll (or bank angle) information. The left-hand lights illuminate during left turns and the right-hand lights during right turns. Both sets of lights off indicates relatively level flight. In a study (12) that compared pilot performance with cue lights in two dissimilar aircraft simulators, the relationship between bank angle and cue lights was as follows:

Convair 340	Boeing 720	Cue Light Illumination	Flash Duration
0° - 30°	0° - 1-1/2°	None	
30° - 100°	1-1/2° - 10°	One Flash/Sec. (Green)	.125 Sec/Flash
100° - 180°	10° - 22°	Two Flashes/Sec. (Green)	.25 Sec/Flash
180° - 220°	22° - 26°	Steady (Green)	
220° - 90°	26° - 90°	Four Flashes/Sec. (Red)	.15 Sec/Flash

# Peripheral Cue Lights (Reference: 23)

The display consists of two banks of five green light emitting diodes (LED's) mounted on a facplate worn by the pilot (Fig. 10). Although the figure shows the lights in a horizontal orientation, the LED banks are capable of being rotated to a vertical position. The LED's are also capable of displaying either a steady light or a yoked in series strobe light.

The lights present heading cues whenever heading is out of tolerance one degree or more. In order to null the unilateral signal the pilot must make a heading correction in the direction of visual stimulation. In the stroke mode the magnitude of correction required is a function of flash rate.

# Glide-slope" Peripheral Display (Reference: 6)

The display consists of two 21-inch televisions each displaying horizontal alternating black and white lines 3-4 inches wide. The televisions are located on each side of the pilot such that the midpoint of each screen is in line with the pilot's eyes and the distance between them 40 inches (Fig. 11). The peripheral display supplies glide-slope information. For example, as the aircraft was turned to the glide-slope, the lines move upward on the television screen and as the aircraft moves downward relative to the glide slope, the lines move in an upward direction. The lines remain stationary whenever the aircraft is in a level movement relative to the glide slope. The ratio of the line movement to rate of glide-slope deviation is: 1.8 lines/sec = 100 ft./sec.

Investigation of the effects of peripheral cue lights on pilot performance (10, 11, 12) yielded these findings:

- (1) Improved performance in maintaining wings level flight;
- (2) Less time flown below glide slope as compared to that when all instruments, including the command bar function of the Collins FD 100 attitude indicator, were used;
- (3) Comparable performance in maintaining position within one dot of the localizer/glide slope centerline, with or without the attitude indicator;
- (4) Safe instrument approaches with a failed attitude indicator using the vertical speed indicator (primarily for pitch control);
- (5) Improved performance in recovery from unusual attitudes with another control application less pitch oscillation, reduced airspeed and altitude variation and less time required to return to a wings-level attitude with no reversal;
- (6) Subjects adapted to use of the peripheral vision cue lights quickly;
- (7) Testing of lateral discrimination of the peripheral cues when central vision was fixated to the right, indicated cues were recognizable by the left eye at a maximum of 90° and the right eye at a maximum of 62°;
- (8) Cue lights were also found to be discriminable at vertical viewing angles of between 20° - 31°;
- (9) A comparison of pilot performance while using the peripheral vision cue lights in two dissimilar aircraft simulators (i.e., Convair 340 and Boeing 720) yielded no significant differences;
- (10) When peripheral vision cues were added to the instrument display environment, flight performance was improved, particularly when additional tasks were added to the pilot's flight duties.

Findings based on testing in a Singer-Link GAT-1 Simulator which closely simulates the F-4 aircraft (23) include:

- (1) None of the analyses produced statistical main effects for differences between the two types of peripheral signals;
- (2) With regard to heading deviations, the only significant difference was between the normal round dial and redundant peripheral signal (compass) conditions, with the redundant condition having a smaller average error than the normal instrument condition; and
- (3) The average number of overcorrections were significantly greater in the peripheral signal only condition than the normal round compass dial condition.

Conclusions based on evaluation of the display during glide-slope simulations (6) include:

- (1) "By providing rate information to the pilot through the motion of horizontal black and white lines displayed in the peripheral vision, performance on a glide-slope task can be improved for most pilots."
- (2) "A peripheral display as used in this study not only improves performance on the glide-slope, but also reduces the stress placed on the pilot when under a heavy workload."
- (3) "By the use of a peripheral display which supplies rate information, improvement on a glide-slope task is attained by giving the pilot an indication of the necessary control input that is needed to correct for an error in glide-slope deviation."
- (4) "A small number of pilots will be unable to receive inputs from a peripheral display and will be unable to improve their performance with its use."
- (5) "A second-order critical task can be effectively used to evaluate peripheral displays which provide rate information and to determine the capability of an individual to use this type of display."



Figure 2. The peripheral vision horizon display (PVHD).

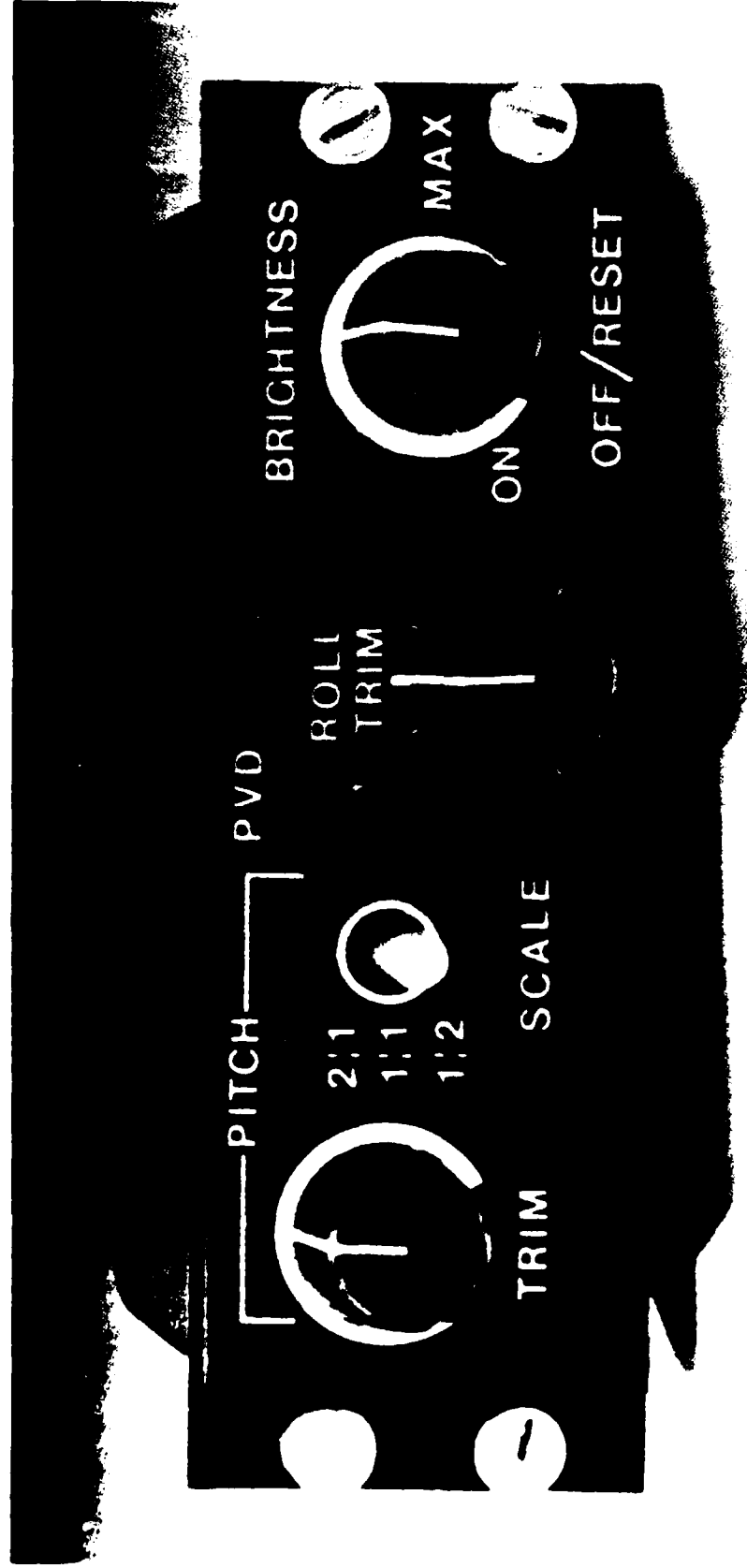


Figure 3. The PVHD control panel.

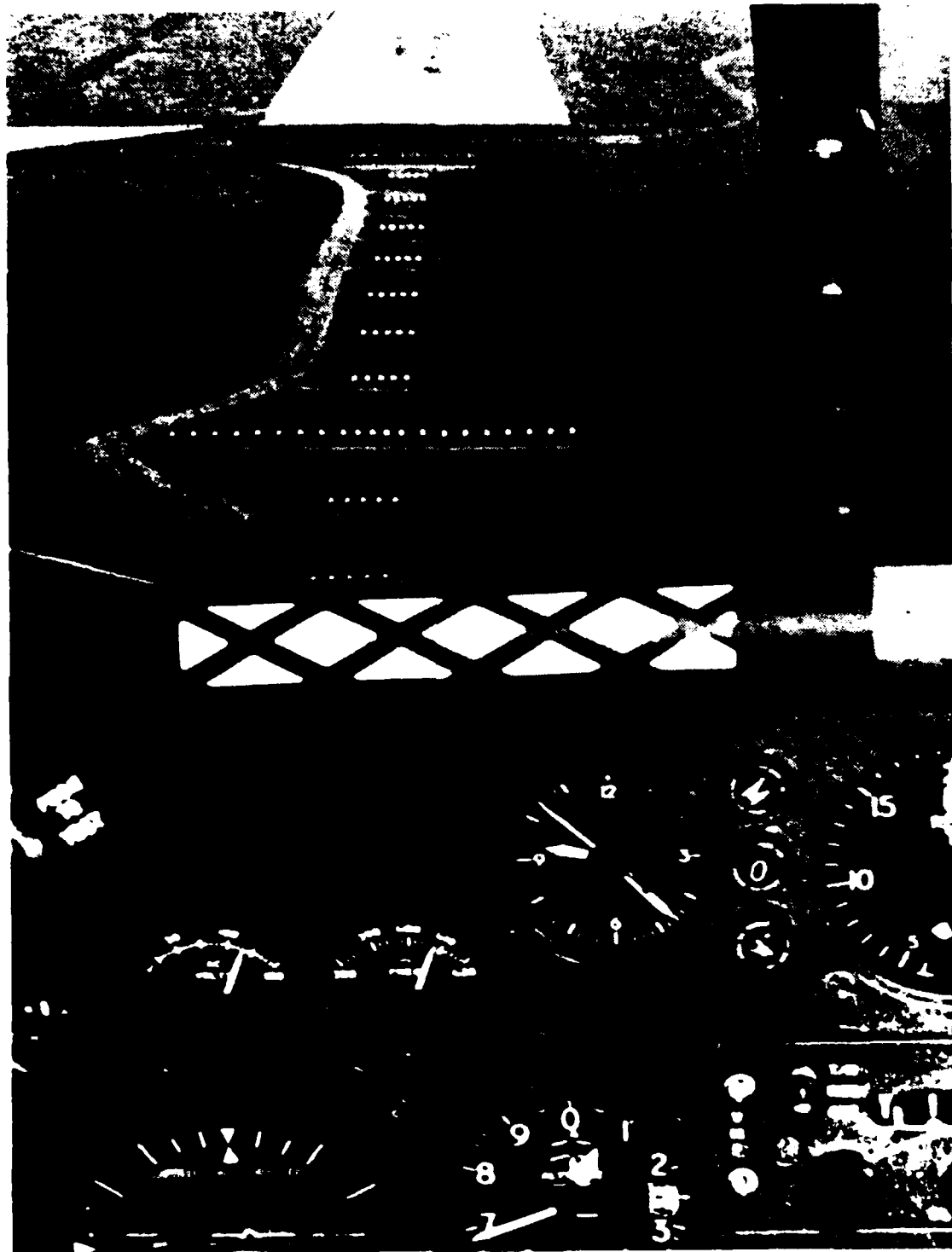


Figure 4. Prototype installation of the peripheral command indicator illustrating its preferred mounting on the glare shield directly in front of the pilot.

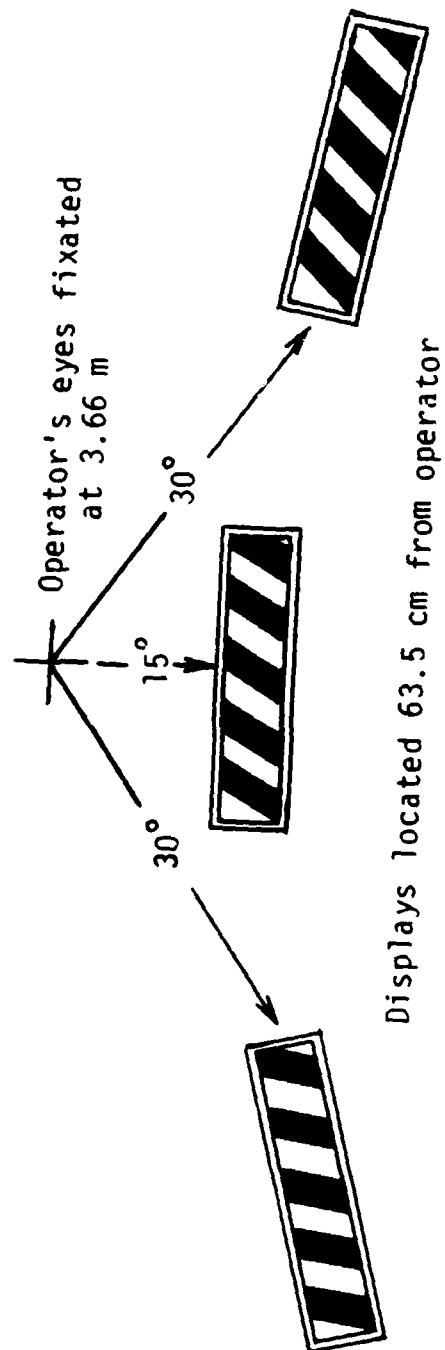


Figure 5. Location of PVHD's in visual field.

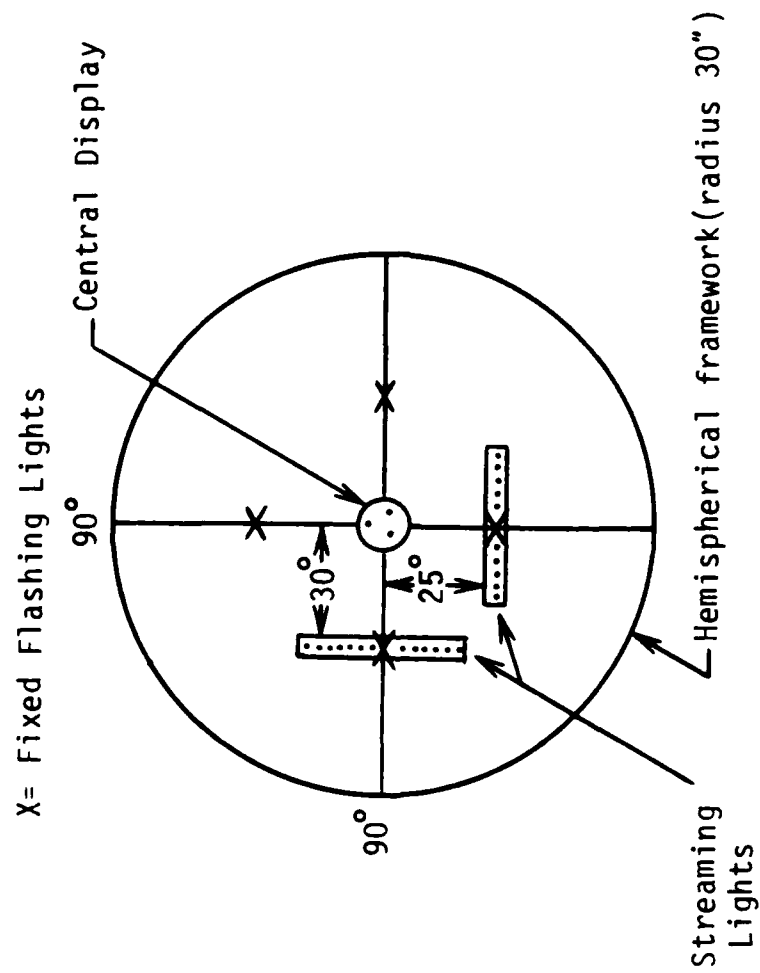


Figure 6. The framework of the simulator showing the layout of the displays. The angles shown were subtended at the subject's eye by the center of the curved framework of the hemisphere and displays attached to the framework.



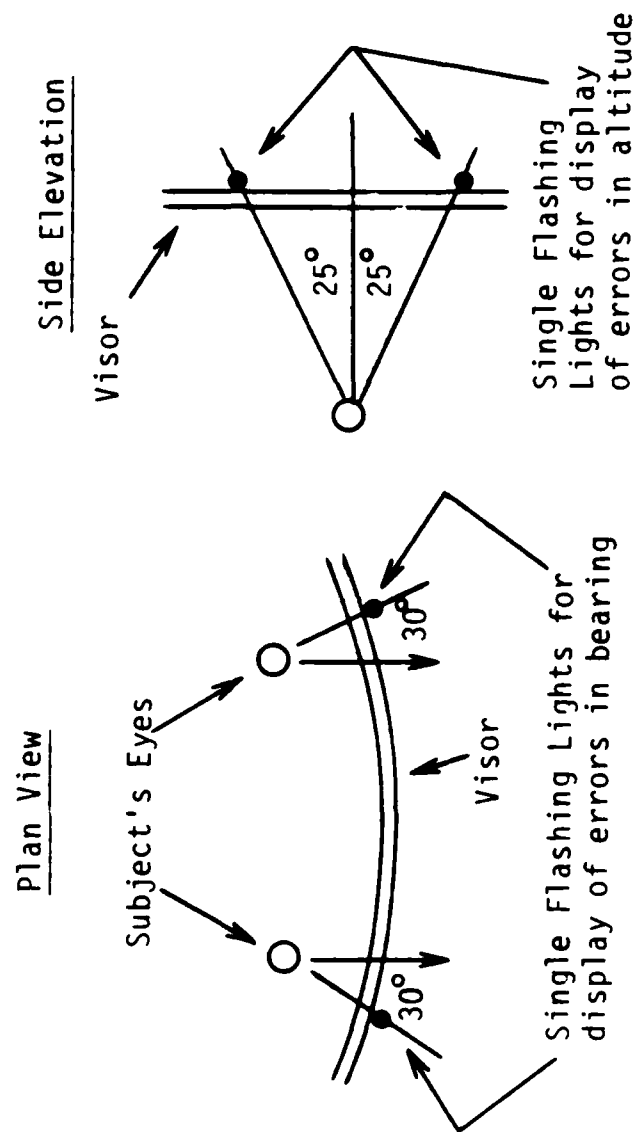


Figure 7. Position of flashing lights on the helmet.

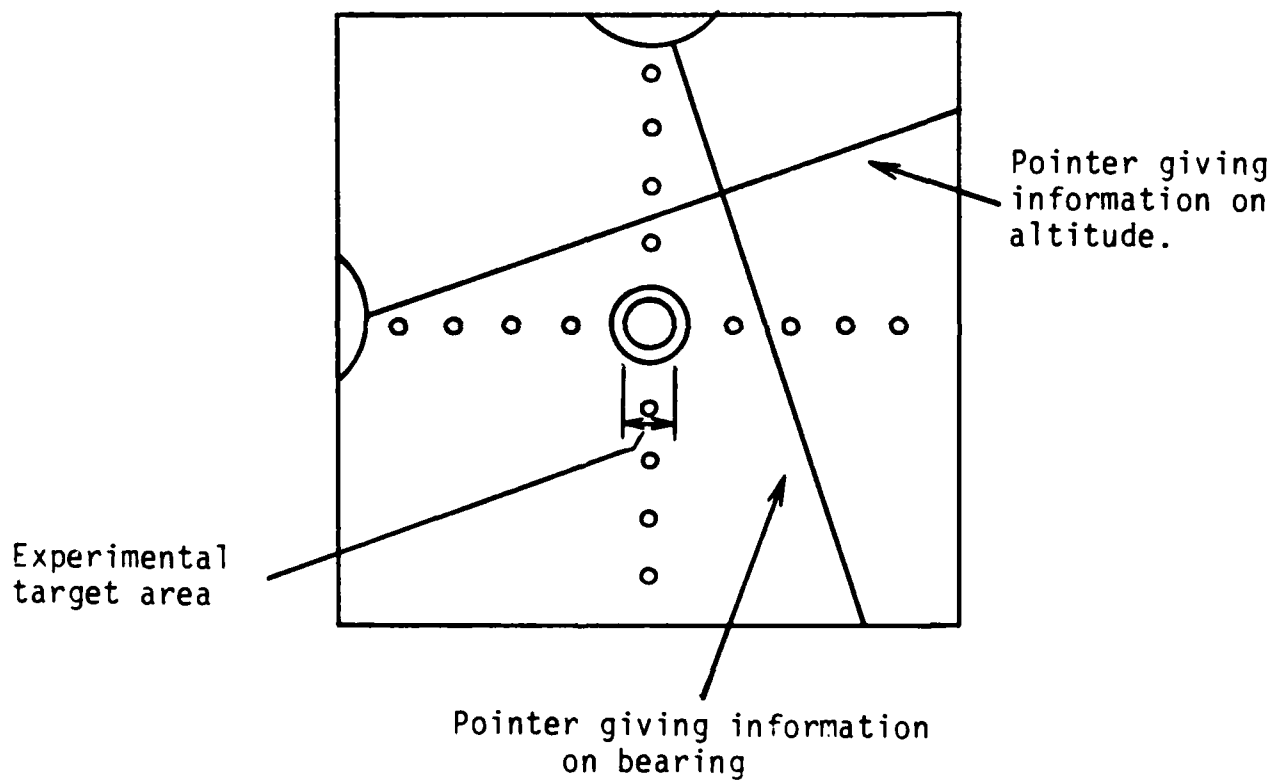


Figure 8. The ILS meter display.

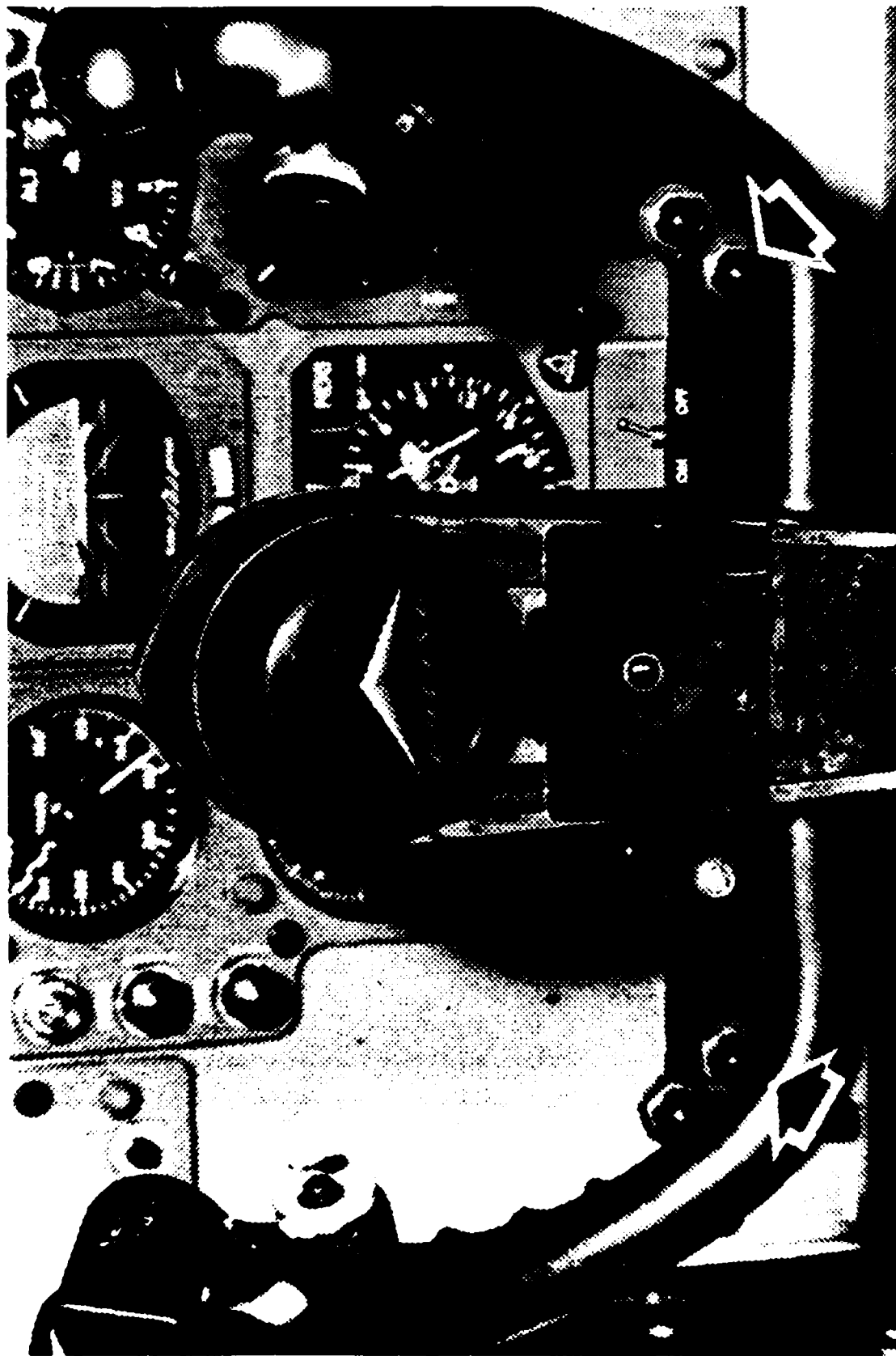


Figure 9. Location of the peripheral cue lights on the pilot's control wheel.

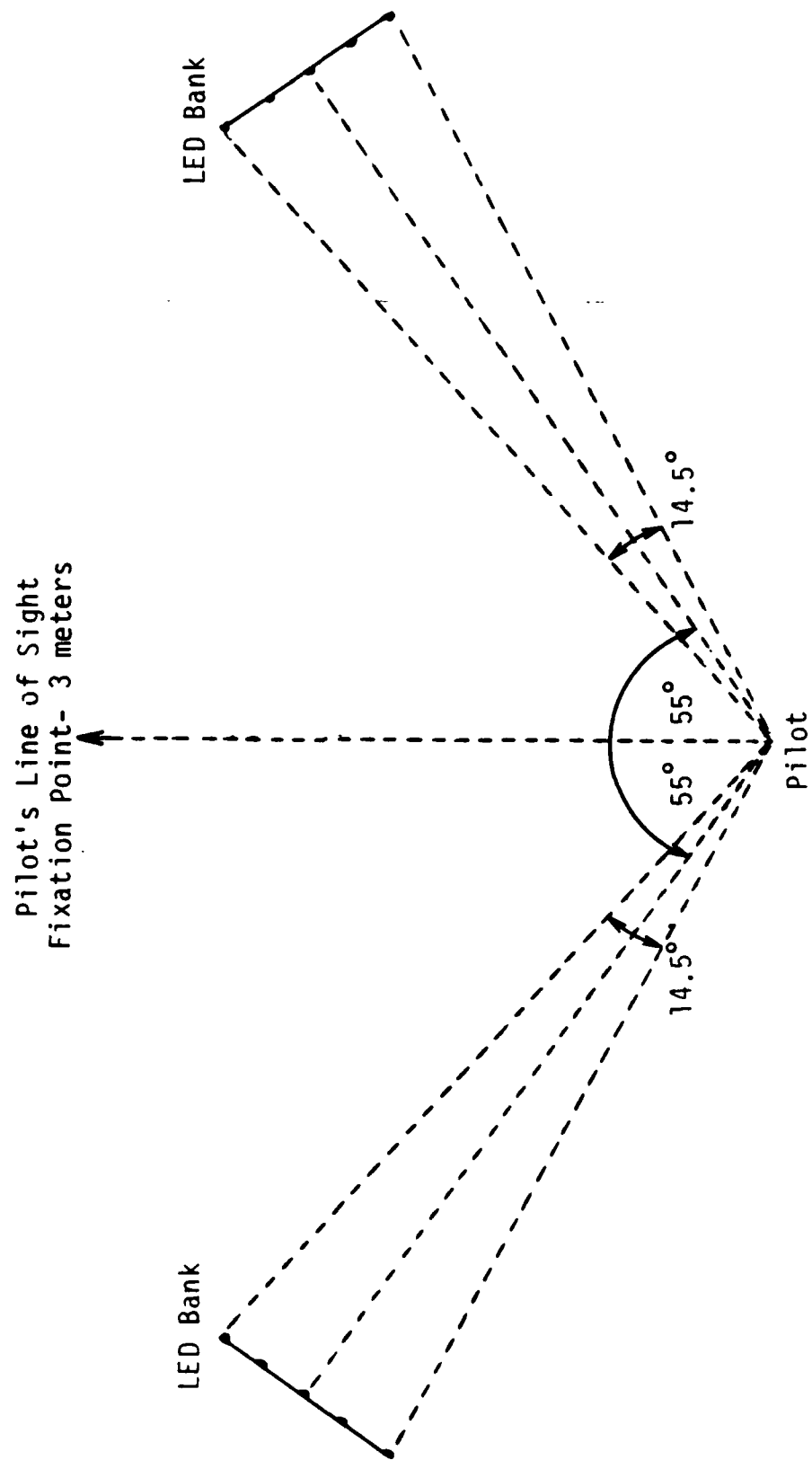


Figure 10. Orientation of the peripheral cue lights.

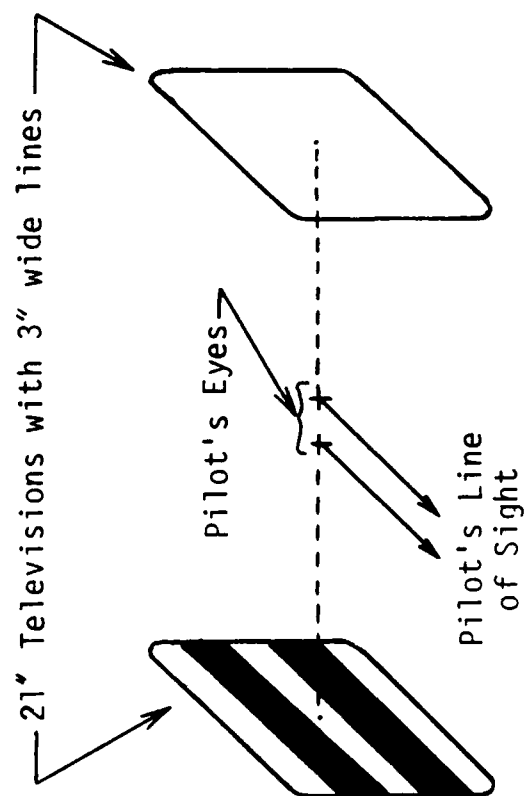


Figure 11. The glide-slope peripheral vision display.

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## APPENDIX

### EXPERIMENTAL OCCLUSION TECHNIQUES

Conrad L. Kraft, Ph.D.

#### INTRODUCTION

Two experimental occlusion methods were developed under this program. The purpose of these developments was to investigate the possibility of conducting experiments on the ground that would stimulate reasonably well relevant dynamics of actual flight. A critical requirement was that foveal vision be occluded and that varying extents and amounts of peripheral vision be permitted the subjects.

The results of the demonstration runs suggest that with further refinement, a useful experimental device can be developed. The results also demonstrated that the video camera method is significantly superior to the more traditional photographic method, primarily because of the brighter image and larger visual field obtained with the video camera method.

#### DEMONSTRATION PHOTOGRAPHIC PERIPHERAL ATTITUDINAL DISPLAY

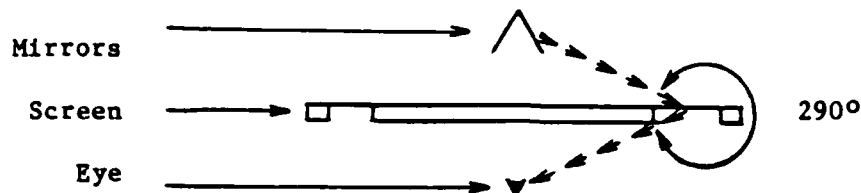
The following paragraphs describe the results of our attempts to use conventional motion picture equipment for development of an experimental device. The films taken for the demonstration were scenes 40 to 60 degrees to the right and left of the direction that the car was traveling. The location of the shooting was open country, a flat "glacial plane" crossed by an east-west road. The sun had a +60 degree elevation and an azimuth slightly west of south.

Perturbations from the straight-ahead camera angle were introduced to change apparent attitudes. "Pitch" changes were introduced by tilting the camera and mirrors up and down within the range of 0 to 10 degrees from horizontal. "Yaw" changes were introduced by rotating the tilt-pan head either left or right also within a limit of 10 degrees. "Roll" was simulated by tipping the camera and mirrors to either side. The tilt-pan head had a worm drive mechanism that allowed these movements to be introduced relatively slow. Fast changes were introduced by changes in the road surface and of course could not be programmed. "Climb" and "descent" were simulated by selecting a steep hill and driving up and down it while maintaining a horizontal position of the camera and mirrors.

The projection system leaves much to be desired. The shortest projection lens available was of a much longer focal length than the 7.5 mm wide-angle taking lens. Therefore, projecting back through the angled mirrors spreads the images very rapidly. This system imposes a short viewing distance, 16 in., and gives small peripheral visual fields, roughly 15 X 18 degrees at an



average eccentricity of 35 degrees. The major limitation is the brightness of the images, due to the line of projection being 290 degrees from the average ray returning toward the observer's eye. (See the following sketch.) The Polacoat screen is designed to provide good viewing brightness out to about 105 degrees. These considerations required evaluation under very low ambient illuminance.



The dynamic motion of the motion pictures taken and displayed with this demonstration apparatus did produce sensations of each of the perturbations introduced by the methodology. This result was true despite the low brightness, very small object images sizes for the retinal position, and the equipment limitations of the small peripheral field of view. "Roll" was most easily perceived, and "pitch" and "yaw" were similar and intermediate in ease of perception with "climb" and "descent" the least easily seen. The order of "ease of perception" may be due to the dependence of these perceptions on the field of view. For example, "roll" imposes more rapid and counter lateral changes in the streaming of the images while "descent" imposes slower and common (within the two peripheral scenes) changes in the "streaming" of the images. The latter would be enhanced if the "streaming" were extended over a larger field of view.

The results of this first attempt were encouraging enough to cause us to look for ways to handle the brightness and field of view problems. The results of that search are discussed in the following section of this appendix.

#### DEMONSTRATIONAL VIDEO TAPE PERIPHERAL ATTITUDINAL DISPLAY

The data gathered with the photographic version of this Peripheral Attitudinal Display indicated that a brighter image and larger peripheral visual fields would provide a stronger perceptual effect. To obtain these modifications within a reasonable time and budget, a video tape version was developed and tested.

Two video cameras with similar characteristics, but of different manufacturers, were mounted on the tilt-pan head and automobile mounting used in the photographic version. The left camera was a Panasonic (color video) Omnipro fitted with a six-power zoom lens and electrically connected with a Magnavox Escort (8 hr) VHS recorder. The right camera was a General Electric (GE) (color video) fitted with an identical lens 1:1.4, 12-72 mm zoom. The GE camera was attached to a Panasonic VHS Omnivision, 2-4-6 hr recorder. The cameras are shown as mounted in Figures A-1, A-2, and A-3, and the recorders

as carried behind the two car seats as shown in Figure A-4. Each VHS was recording on a JVS Dynamic T-120 Super HG video cassette.

The empirically determined field of view of these cameras and the fitted zoom lens when set at the widest angle setting, or 12 mm focal length, was 32.4 degrees. The cameras were each pointed 40 degrees right and left of the center line of the car. The horizontal plane was determined with a Mayes Level and Angle Finder. The peripheral fields were therefore between 23.8 and 56.2 degrees horizontally and 16 degrees above and below horizontal, or 26 degrees in the vertical extent.

The location of the filming was two roads traversing a flat "glacial plane" in the east-west direction. The sun was between 30 and 50 degrees in elevation and 50 to 80 degrees west of south. Perturbations from the straight-ahead camera angle were introduced to change "streaming effect" of the scene in pitch, roll, and yaw. "Pitch" changes were introduced by tilting the cameras up and down within the range of 0 to 10 degrees. (An occasional use of 20 degrees was tried but not re-recorded.) "Yaw" changes were introduced by rotating the tilt-pan head either left or right. "Roll" was simulated by tipping the cameras to either side. The tilt-pan head had a worm drive mechanism that allowed these movements to be introduced relatively smoothly and at different speeds. In most runs we tried to introduce a slow, medium and fast version of one of these perturbations. "Climb" and "descent" were introduced only once by selecting a steep hill and driving up and down it while maintaining a horizontal position of the cameras. Some 15 runs were made at speeds of 30 to 40 km/hr and two to four examples of a single class perturbation were included within the run of 1 min duration.

The original tapes were taken to a professional studio for editing. The demonstration tapes are two in number, one for the right side display and one for the left side. The right side tape has a duration of 6 min and 54 sec. The left side tape lasts for 6 min and 53 sec. The best synchrony is obtained by having both tapes at the beginning of the imagery stationary with the "pause" control active. Then hit the "play" button for the right side imagery 1 sec before the left display has started. The demonstration tapes are comprised of five segments separated by fade outs and fade ins. The five segments are as follows:

- 1) FAMILIARIZATION: Straight and level with no perturbations.  
1':14"
- 2) YAW: Three examples, one each at slow, medium and fast rates.  
1':7"
- 3) PITCH: Two directions, at three speeds, followed by a climbing left turn [ROLL AND CLIMB].  
1':42"
- 4) PITCH: Three speeds and a different scene.  
1':17"
- 5) DESCENT: Descending right turn followed by a "long" straight and level section.  
1':10"

The viewing of these tapes will require the use of two 19 in. (diagonal) televisions and two VHS 1/2 in. cassette tape recorder/playback units. The TV screen should be perpendicular to a line from the observer's eyes at 40 degrees right and left of the straight-ahead line of sight. The set-up provides 47.6 degrees of "unloaded" central vision, where eventually other quantitative central vision tasks could be introduced. In the demonstration device, a piece of "foam core" board with cut outs for each of the televisions will be folded to provide a flat forward field on which will be mounted a photographic replica of an aircraft instrument. (See Fig. A-5.)

In making a demonstration to a pilot, or other individual, the procedure may be to ask him/her to maintain fixation on the photographic replica of the instrument--i.e., to maintain a straight-ahead line of sight and, while doing so, verbally respond whenever he/she sees the "flow field" in the periphery not matching the direction that the car is traveling. If he/she flies, the individual may add recognition of the type of perturbation that has been introduced--i.e., pitch, roll, yaw, climb and descent.



Figure A-1. Video cameras on a tilt-pan head and automobile mountings.



Figure A-2. Mounted video cameras.

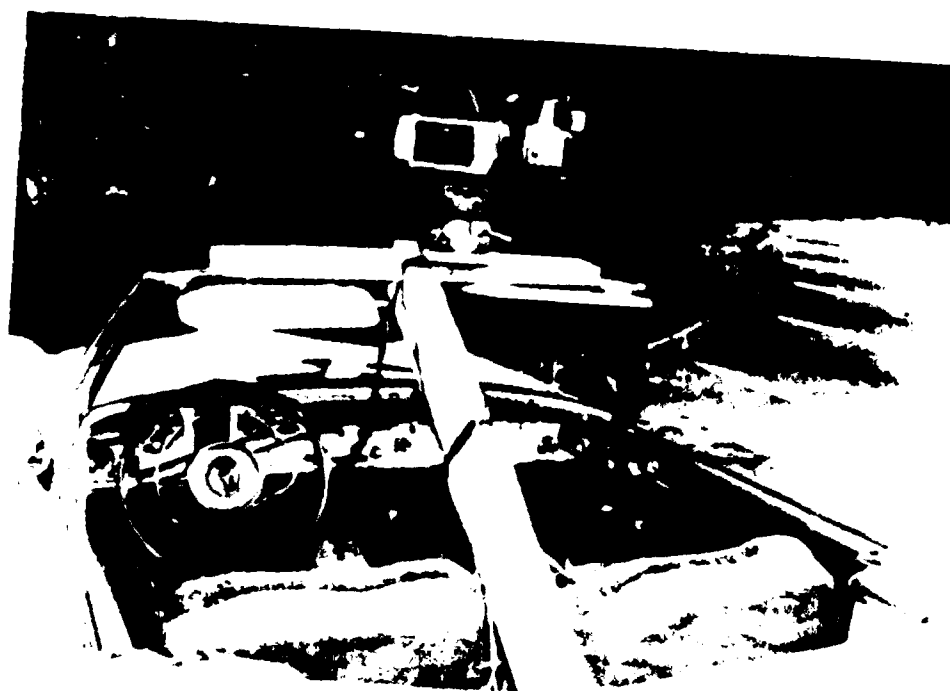


Figure A-3. Mounted video cameras.

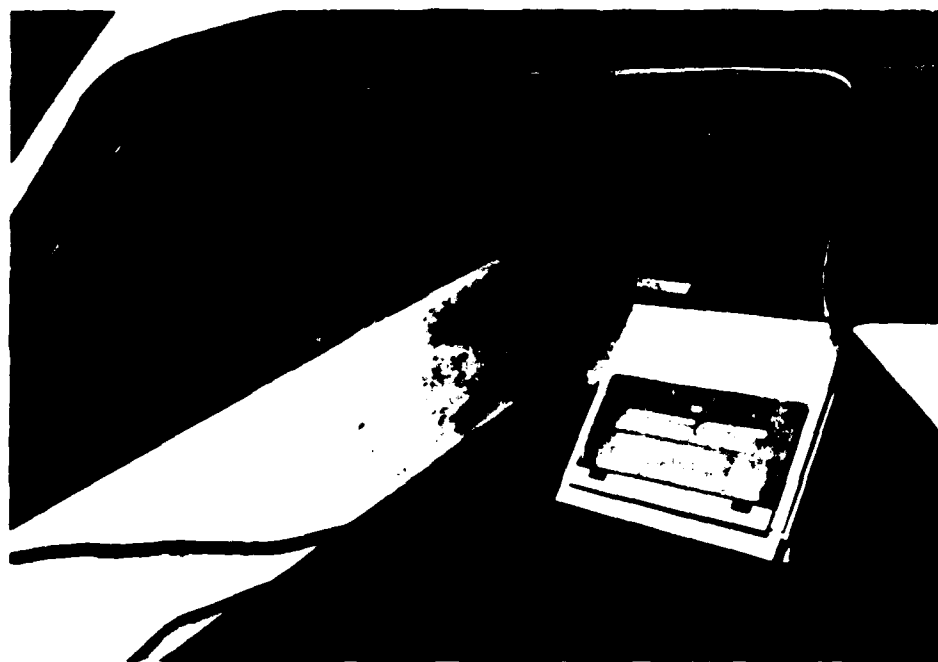


Figure A-4. Video cassette recorders.

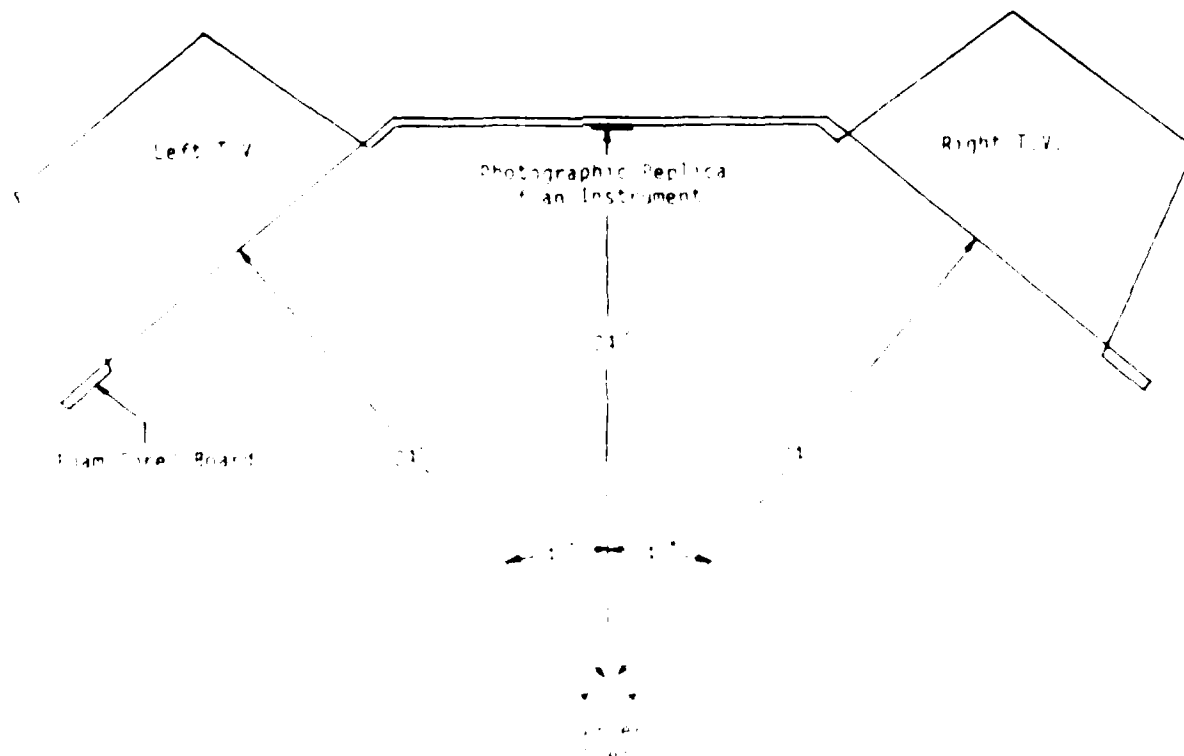


Figure A-5. Diagram of the video recording system.

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